A REVIEW AND EVALUATION OF POTENTIAL DATA COLLECTION METHODS FOR MONITORING SUBSIDENCE OVER LONGWALL WORKINGS IN SUBMARINE COALFIELD

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A Review and Evaluation of Potential Data Collection Methods for Monitoring Subsidence Over Longwall Workings in Submarine Coalfield

VOLUME I

BY

JACQUES, WHITFORD AND ASSOCIATES LIMITED

With

ASSOCIATED MINING CONSULTANTS LTD.
McCLELLAND ENGINEERS INC.
CANADIAN SURVEY CONSULTANTS

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MINE SUBSIDENCE

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EXECUTIVE SUMMARY

This report, prepared under the auspices of CANMET, Coal Mine Research Laboratory, reviews and presents methods to monitor coal mine subsidence profiles within the marine environment. Coal mining operations, within the Sydney coalfield, are conducted in the near offshore areas of Cape Breton Island, Nova Scotia. Mine design and longwall layouts are executed using subsidence design criteria, based on seafloor strains, adopted from other coal producing areas of the world. The purpose of this study is to identify means to monitor actual seafloor strains and profiles of rock mass deformation in order to provide data with which to compare subsidence models and to assess the efficiency of the mine design.

Nova Scotia's Sydney coalfield is host to thirteen coal seams of which three are being operated by the Cape Breton Development Corporation using longwall methods. Longwall faces of 100 m to 230 m separated by coal pillars of approximately 70 m operating on a 2m seam may be expected to develop maximum subsidence of up to 1m for single seam extraction. Longwall faces are designed to a maximum seafloor strain of 8.5 mm/m. Mine workings, at depths of 700 m, extend seaward up to 10 km from the shoreline and longterm plans may also consider multi-seam extraction.

Within the proposed project area, water depths range from 25m to 45m with a tidal fluxuation of approximately 1 m. The thickness of seafloor sediments is expected to range from 0 to 8m and is of unknown character. Atmospheric, ice cover and sea state conditions are not expected to be severe and will permit field deployment of instrumentation during the months May to October. Similarly, local fishing operations and the marine transport industry should have little effect on the proposed monitoring program.

The character of rock deformation due to subsidence is identified as a symetrical trough, centred over the longwall face extending 0.7 times the depth beyond the limits of mining. Critical, or maximum subsidence, is a function of the mine geometry in terms of longwall face length, pillar width, seam thickness and depth of the coal seam below surface. Subsidence movements start while the mining is in progress and may proceed for as long as 18 months after operations cease.

Subsidence monitoring projects conducted both from surface and underground, using conventional surveying and geotechnical instruments are briefly described as well as automated data collection devices. The use of geophysical techniques is not expected to be successful in this application. Design criteria are developed for the conduct of a monitoring program within the marine environment in terms of site selection, design and layout of stations, instrumentation required, and observations frequency.

Direct monitoring instrumentation is commercially available for the measurement of horizontal and vertical movements, and tilt within the marine environment. A triangular arrangement of measurement stations (cluster) sited on the seafloor is recommended to measure deformations in both the longitudinal and transverse directions relative to the longwall face. Eight such clusters linked by automatic data acquisition and transmission systems are proposed to complete the task. Subsea acoustical methods and sea surface mapping systems are also discussed, although development may be required to enhance the resolution of these systems.

Survey control, drilling, and diving support will be required during deployment of any systems proposed for use. Remote operation and interrogation of any monitoring scheme using portable power supplies, telemetry and/or hardwire links to shore with computer data acquisition and storage is feasible.

Capital cost estimates range from $176,000 for the least accurate sea surface system to $826,000 for the most accurate direct monitoring system described. Lease or contract options should also be considered. Operational costs are expected to be minimal.

Résumé exécutif

Le rapport suivant a été réalisé sous les auspices de CANMET, Laboratoire de recherches houillères, et il fait l'étude des différentes méthodes de surveillance sur les profils d'affaissement houiller sous la mer. L'exploitation de charbon à l'intérieur du bassin houiller de Sydney se trouve sous les eaux littorales du Cape Breton en Nouvelle-Écosse. Les plans de mine et de front de taille longwall sont projetés à l'aide de critères sur l'affaissement. Ces critères ont été établis d'après les déformations du fond marin et les opérations houillères à travers le monde. Cette étude a pour but de déterminer les méthodes de surveillance reliées aux déformations du fond marin et aux profils de déformations de la masse rocheuse réelles, qui fourniront des données pour nous aider à les comparer avec ceux des modèles d'affaissement et évaluer l'efficacité des plans de mine.

Le bassin houiller de Sydney comprend treize filons houillers dont trois sont présentement exploités par Cape Breton Development Corporation utilisant les méthodes longwall (attaque en pleine section). On prévoit que les fronts de taille longwall de 100m à 230m séparés par des piliers de mur d'environ 70m d'épaisseur, et exploité sur un filon de 2m pourrait causer de l'affaissement atteignant jusqu'à 1m pendant le procédé d'extraction d'un seul filon. Les fronts de taille longwall sont conçus pour atteindre un maximum de déformation du fond marin de 8,5mm/m. À une profondeur de 700m, les travaux miniers s'étendent à 10km du rivage. Les objectifs à long terme de ce projet prendraient même en considération le procédé d'extraction à filons multiples.

À l'intérieur de la région mise à l'étude, on note que les profondeurs d'eaux varient entre 25m et 45m tenant compte d'un marnage d'à peu près 1m. Les propriétés des sédiments qu'on travail, il serait bon d'installer huit groupes de ce genre reliés par des systèmes de transmission et de recueil des données automatisés. Le rapport discute également des méthodes acoustiques sous-marines et de la cartographie du fond marin, quoiqu'on requiert plus de recherche pour améliorer la résolution de la cartographie.

Le contrôle d'arpentage, le forage et les services de plongeurs seront nécessaires au déploiement des systèmes proposés dans le rapport. Il sera possible de se servir des opérations et des interrogations du télédétecteur durant la surveillance en utilisant une alimentation en électricité portative, la télémétrie, et des câbles en métal rejoignant la côte, avec l'information de l'ordinateur recueillie et mise en réserve.

On estime que les dépenses en capital varieront entre 176 000$ pour le système sur le fond marin (le moins précis) et 826 000$ pour le système comprenant la surveillance directe (le plus précis). Le choix d'obtenir un bail ou un contrat est à considérer. Les dépenses de l'opération de ce projet seraient minimales.

retrouve sur le fond marin sont inconnues, mais on suppose que leur épaisseur varie entre moins de 1m et 8m. Durant la période de l'année comprenant les mois de mai, juin, jusqu'en octobre, les conditions atmosphériques, les conditions de la mer et de la glace ne sont pas dures, et même, elles permettront le déploiement des instruments sur le terrain. Pareillement, on ne prévoit aucun problème durant le programme de surveillance relié au transport maritime ou à la pêche locale.

On identifit une des propriétés de la déformation de roche causée par l'affaissement comme étant une dépression symétrique située au milieu du front de taille longwall et s'étend 0,7 fois la profondeur au delà des limites de l'exploitation minière. La quantité d'affaissement est fonction du plan de mine en terme de la longueur du front de taille longwall, la largeur du pilier, l'épaisseur du filon et la profondeur du filon houiller sous la surface. L'affaissement se manifeste pendant le déroulement des travaux miniers, et peut continuer à avancer jusqu'à 18 mois après la cessation des travaux.

Le rapport donnera un aperçu des projets de surveillance sur l'affaissement menés à la surface et souterrainement utilisant des instruments topographiques et géotechniques conventionnels, ainsi qu'une courte description des appareils automatisés de collection des données. Il est possible que l'emploi des techniques géophysiques n'aurait pas de succès dans ce genre de projet. Les critères du plan sont établis pour la programmation de la surveillance à l'intérieur du milieu maritime en rapport avec la sélection d'un lieu, le dessein et le plan des postes, l'appareillage requis et la fréquence d'observation.

Disponible sur le marché, l'appareillage de surveillance directe mesure les mouvements horizontaux et verticaux ainsi que l'inclinaison des sédiments marins. Les postes de mesurage arrangés en triangle (dans un groupe) sur le fond marin sont recommandés pour la mesure des déformations des axes longitudinal et transversal du front de taille longwall. Pour compléter le

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1.0 BACKGROUND AND PROJECT RATIONAL

1.1 Project Rational

Mining of coal by longwall methods is known to initiate subsidence of the overlying strata. The degree of subsidence varies with the size of unsupported opening produced by the extraction and the stresses induced by the weight of the overburden. When the coal measures occur as submarine, the degree of subsidence and induced tensile strains may carry special significance, in terms of seawater intrusion: As of January, 1984 the Cape Breton Development Corporation (CBDC) operate three longwall coal mines, Lingan, Prince and No. 26 collieries. Jacques, Whitford and Associates Limited were awarded a contract to prepare a summary compilation and evaluation of potential methods of collecting seafloor and/or seafloor/bedrock subsidence data over submarine coal mines operating by longwall methods.

The technical concerns to be addressed were outlined by the statement of work which has been attached as Appendix 1-1. The document requested the preparation of a summary description and evaluation of current subsidence instrumentation systems which could detect complete undersea subsidence profiles.

1.2 Study Participants

The contract was awarded in February, 1984, under the direction of Dr. T. Aston, Scientific Authority. The prime consultant on the project, Jacques, Whitford and Associates Limited (JWA), assigned Mr. J.A. Amirault, P.Eng. as project manager. Other participating firms, and key personnel involved were as follows:

: Jacques, Whitford and Associates (JWA)
    Dr. L. Baikie - Senior Geotechnical Engineer
    Mr. G. Sheppard - Mining Engineer

: Associated Mining Consultants (AMCL)
Dr. D. Forrester - Senior Mining Engineer
Mr. C.H. Shadbolt - National Coal Board (NCB) Subsidence Engineer

: Canadian Survey Consultants (CSC)
Mr. C. Thompson, P.Eng. - Field Supervisor
Mr. T. Harding, P.Eng. - Survey Engineer
Mr. D. Steeves,

: McClelland Engineers (MEI)
Mr. H. Dalrymple, P.Eng. - Senior Electronics Engineer
Mr. L.V. Babbs, P.Eng. - Mechanical Engineer

1.3 Conduct of the Study

The overall study was managed and co-ordinated by JWA with the other firms contributing technical detail in areas of respective expertise. Liaison meetings and frequent conversations with the Scientific Authority and subconsultants assured proper direction and progress of the project.

AMCL provided technical detail on mining aspects prepared and a summary of methods currently used to monitor coal mine subsidence on land as well as developing criteria for the submarine application.

JWA compiled and reviewed data on site conditions, environmental factors, station layout and geotechnical instrumentation as well as prepared the overall study conclusions. As project managers JWA was also responsible for the production of all interim and final reports.

MEI provided commentary on the application of the geotechnical instrumentation within the marine environment, data acquisitions, storage and transmission as well as the use of geophysical methods.

CSC dealt with issues relating to surveying methods both within the mines and on the sea surface, operating instrumentation on the seabed, and the use of indirect methods of surveying and measurement under water.

Although some of the work proceeded concurrently much of the detailed work was dependent on the AMCL report which defined the parameters of the required monitoring program.

1.4 Organization of Report

The statement of work clearly requested that the report not deal with subsidence mechanisms but rather present various options available for submarine monitoring of subsidence profiles. It is necessary, however to briefly comment on the reason subsidence occurs and also to present facts on the Sydney coalfield and the longwall coal mining operations being conducted.

This report is presented in eight sections. Section 1 provides the details of the study with respect to project rational, participating firms and report organization. Sections 2 and 3 outline the Sydney coal basin, the collieries operating within the basin and presents site specific conditions for the region to be monitored such as bathymetric, seastate, socioeconomic and environmental data. Section 4 reviews and discusses ground subsidence, current land based instrumentation for subsidence monitoring and the design criteria for submarine subsidence monitoring. Direct monitoring instrumentation is discussed in Section 5 while positioning and surveying techniques are presented in Section 6. The marine application of subsidence monitoring systems is discussed in Section 7.

The merits of several monitoring systems are presented in Section 8 and also included is a suggestion of the field procedures to be used and preliminary estimates of costs.

The bibliography for the report is located at the rear of this document whereas the appendices for each section are attached as a second volume.

1.5 Acknowledgements

The authors gratefully acknowledge the willing participation of all those assisting in the assembly of data and preparation of this report. We particularly wish to thank Dr. T. Aston, Scientific Authority for direction and guidance during the planning and conduct of the study. Personnel from CBDC generously provided technical detail on the collieries and information on offshore bathymetry and sediment thickness. Other federal government agencies such as Environment Canada and Fisheries and Oceans also supplied relevant information.

2.0 SYDNEY COALFIELD

2.1 Sydney Coalfield

Location

The Sydney coalfield is situated in northeastern Nova Scotia on and offshore Cape Breton Island (Figure 2-1). It consists of two sectors: a small land area of about 520 km^2 and also a region where mining is carried out below the sea. Both form part of a large Carboniferous basin that extends north towards Newfoundland, and to the east, occupying some 36,300 km^2. It is referred to as the Sydney Basin and its extent was determined using shipboard geophysical and acoustic methods (Hacquebard, 1983).

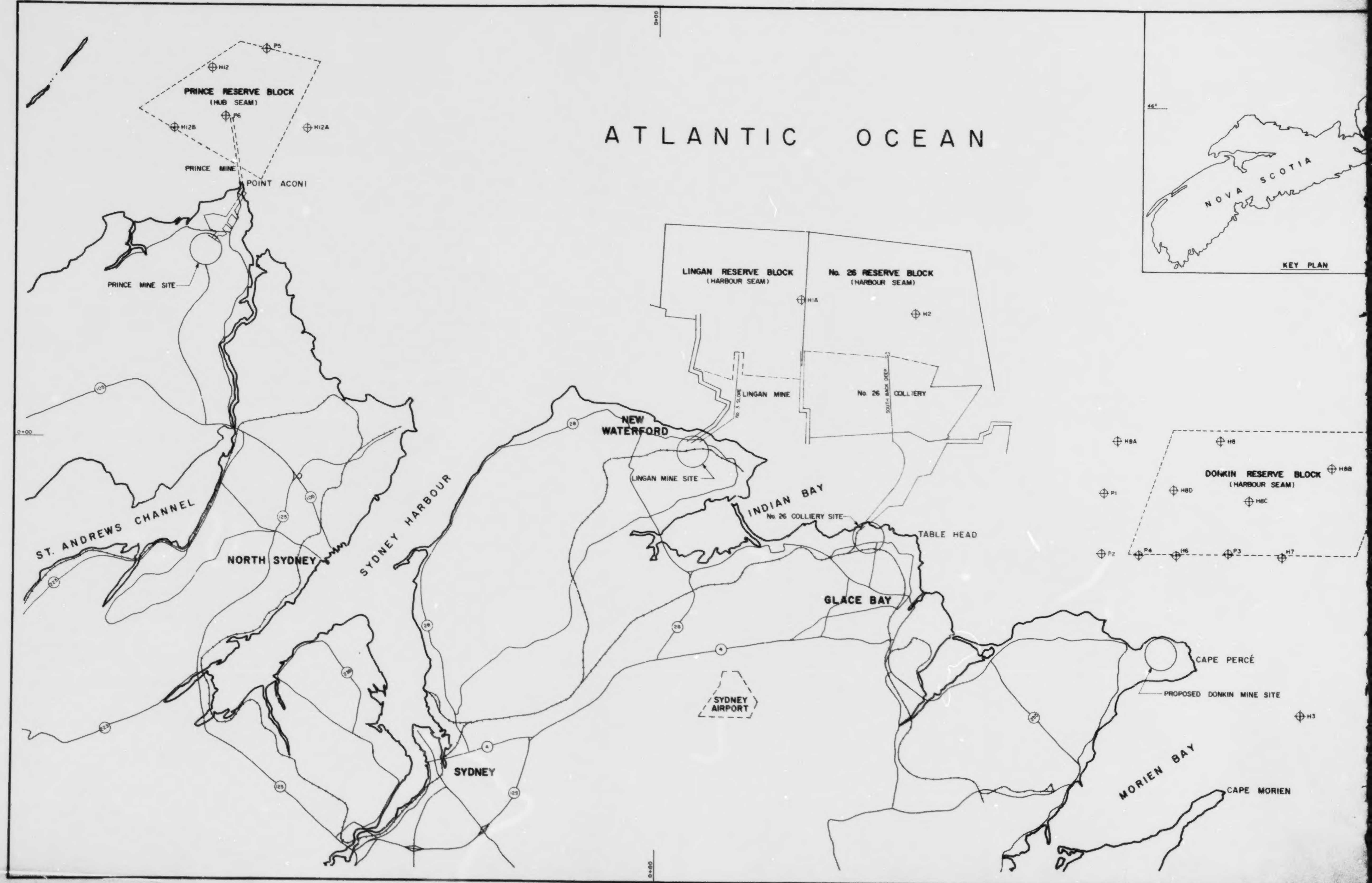
Geology

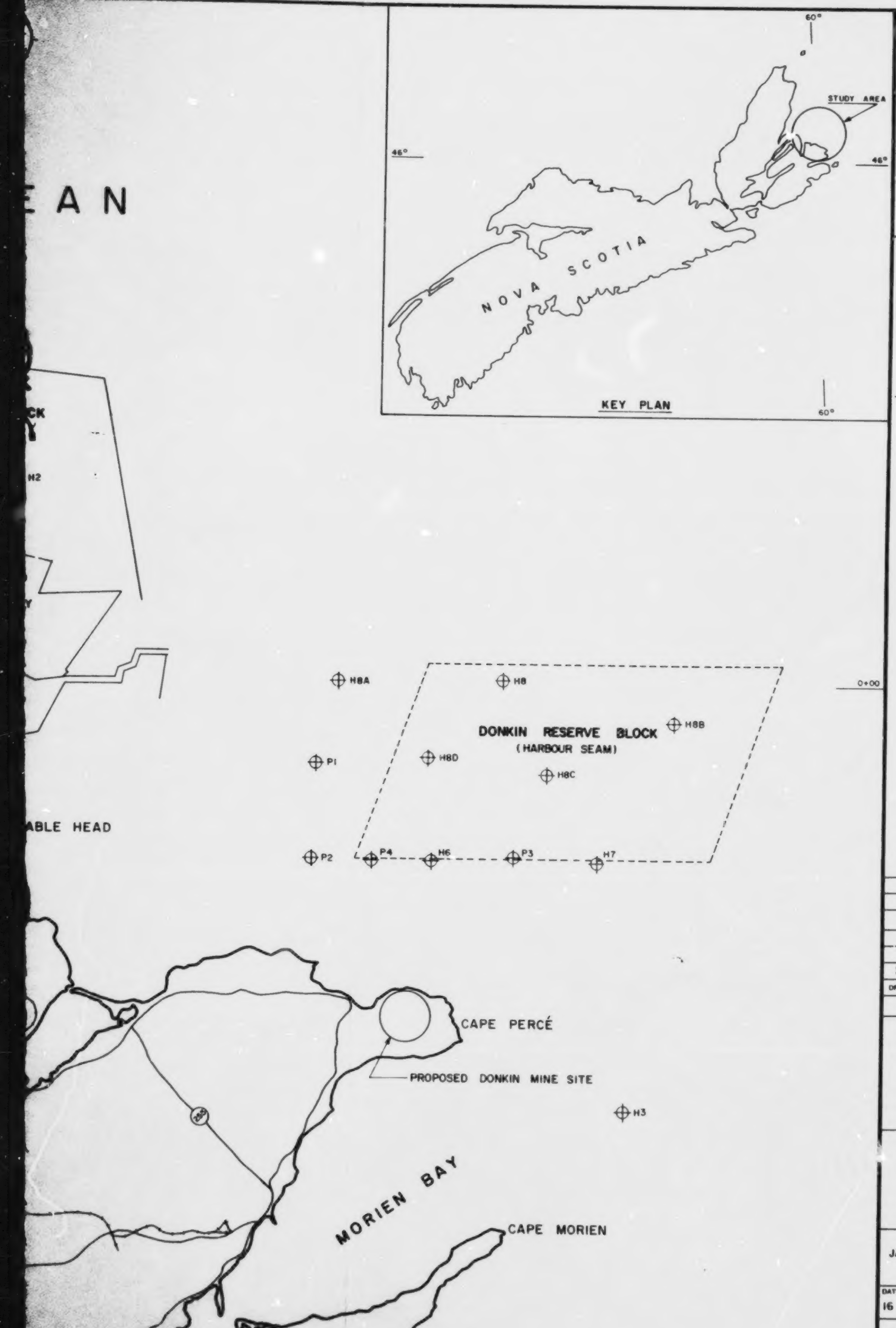
Surficial Geology

There is only a limited amount of information available regarding the sediment cover on the offshore of Cape Breton within the zones to be monitored for subsidence. Figure 2-2 presents the sediment thickness within the study area and indicates that these values range from 0 (outcrop) to 20 metres. Sediment thickness data is not available for the area covering the Donkin Mine Reserve. Areas of excessive sediment thickness are interpreted as filled in basins or depressions.

The on-land surficial formations in the area consists of a glacial till containing grey brown sand and gravel in a matrix of clayey silt. It is speculated that the constituents of the seafloor sediments will be similar to these glacial tills.

There is insufficient information available to permit a precise evaluation of sediment type and character for the purpose of founding geotechnical instruments. A detailed site survey will be required at each monitoring station(s) to determine sediment parameters.


PRINCE RESERVE BLOCK
(HUB SEAM)
P5
H12
H12B
P6
H12A
PRINCE MINE
POINT ACONI
PRINCE MINE SITE
ATLANTIC OCEAN
0+00
46°
NOVA SCOTIA
KEY PLAN
LINGAN RESERVE BLOCK
(HARBOUR SEAM)
No. 26 RESERVE BLOCK
(HARBOUR SEAM)
H1A
H2
No 3 SLOPE
LINGAN MINE
SOUTH BACK DEEP
No. 26 COLLIERY
105
0+00
NEW WATERFORD
28
LINGAN MINE SITE
H8A
H8
H8B
DONKIN RESERVE BLOCK
(HARBOUR SEAM)
H8D
H8C
P1
INDIAN BAY
No. 26 COLLIERY SITE
TABLE HEAD
P2
P4
H6
P3
H7
106
125
SYDNEY HARBOUR
ST. ANDREWS CHANNEL
NORTH SYDNEY
225
GLACE BAY
28
28
4
CAPE PERCÉ
SYDNEY AIRPORT
PROPOSED DONKIN MINE SITE
H3
239
255
223
4
SYDNEY
MORIEN BAY
125
125
CAPE MORIEN
0+00


E A N
CK
H2
ABLE HEAD
KEY PLAN
NOVA SCOTIA
STUDY AREA
46°
46°
60°
60°
H8A
H8
H8B
DONKIN RESERVE BLOCK
(HARBOUR SEAM)
P1
H8D
H8C
P2
P4
H6
P3
H7
0+00
CAPE PERCÉ
PROPOSED DONKIN MINE SITE
255
H3
MORIEN BAY
CAPE MORIEN

LEGEND

⌖ C.B.D.C. EXPLORATION BOREHOLE

0+00 C.B.D.C. MINE GRID

THIS DRAWING FORMS PART OF JACQUES, WHITFORD AND ASSOCIATES REPORT No. M1255 AND SHOULD BE READ IN CONJUNCTION WITH THE REPORT.

NO	DETAILS	DATE
	REVISIONS	

DRWG NO	DESCRIPTION	DATE
320-P	Cape Breton Development Corporation	NOV. / 79
	REFERENCES	

ENERGY, MINES & RESOURCES

SUBMARINE SUBSIDENCE

SYDNEY, NOVA SCOTIA

LOCATION MAP

JACQUES, WHITFORD & ASSOCIATES LIMITED
CONSULTING ENGINEERS

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16 AUGUST '84	1:125,000	V.H. / R.M.

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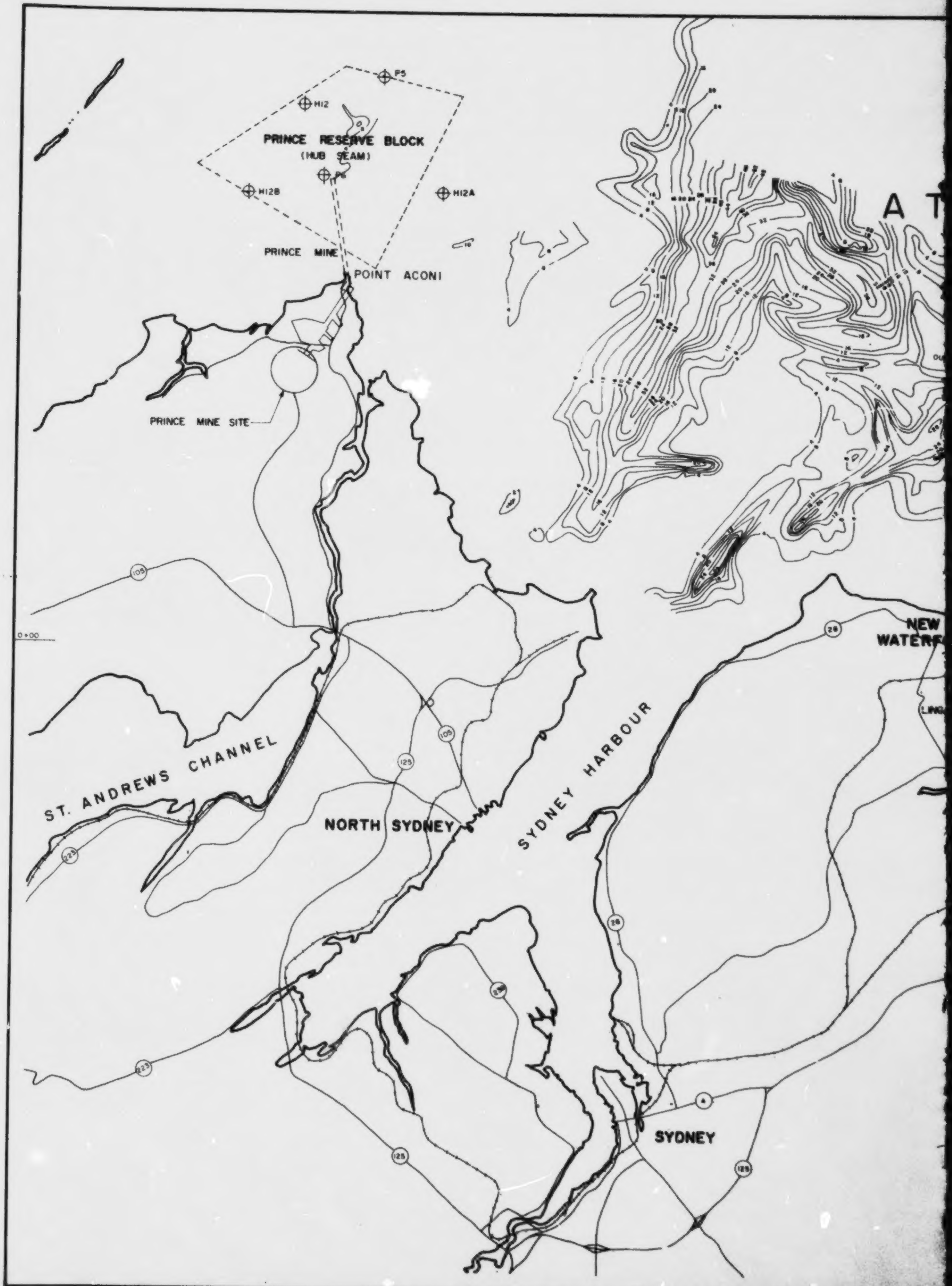
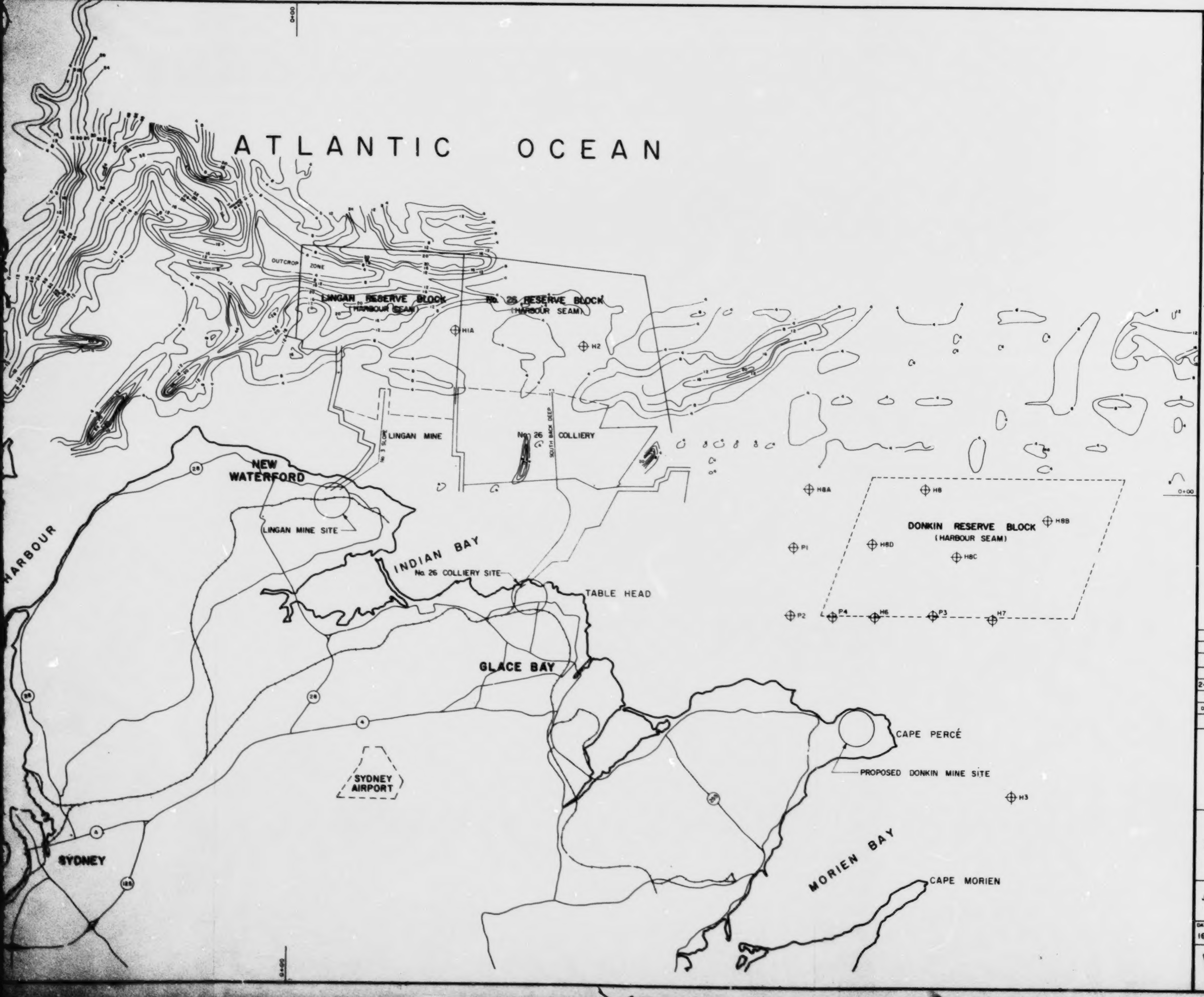
DRAWING NO FIGURE 2-1


P5
H12
PRINCE RESERVE BLOCK
(HUB SEAM)
P6
H12B
H12A
PRINCE MINE
POINT ACONI
PRINCE MINE SITE
A T
0+00
105
NEW
WATERF
28
LING
ST. ANDREWS CHANNEL
SYDNEY HARBOUR
105
125
NORTH SYDNEY
223
28
239
223
4
SYDNEY
125
125


ATLANTIC OCEAN
0+00
OUTCROP ZONE
LINGAN RESERVE BLOCK
(HARBOUR SEAM)
No. 26 RESERVE BLOCK
(HARBOUR SEAM)
H1A
H2
LINGAN MINE
No. 26 COLLIERY
SOUTH BACK DEEP
NEW WATERFORD
LINGAN MINE SITE
HARBOUR
INDIAN BAY
No. 26 COLLIERY SITE
TABLE HEAD
GLACE BAY
SYDNEY AIRPORT
SYDNEY
CAPE PERCÉ
PROPOSED DONKIN MINE SITE
MORIEN BAY
CAPE MORIEN
DONKIN RESERVE BLOCK
(HARBOUR SEAM)
H8A
H8
H8B
H8D
H8C
P1
P2
P4
H6
P3
H7
H3
28
4
125
12

LEGEND

⊕	C.B.D.C. EXPLORATION BOREHOLE
0+00	C.B.D.C. MINE GRID
—12—	SEDIMENT THICKNESS IN METRES (PRECISION ± 2 m)

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NO	DETAILS	DATE

REVISIONS

DRWG NO	DESCRIPTION	DATE
2457-4	Nova Scotia Research Foundation	AUG./79
320-P	Cape Breton Development Corporation	NOV./79

REFERENCES

ENERGY, MINES & RESOURCES

SUBMARINE SUBSIDENCE

SYDNEY, NOVA SCOTIA

SEDIMENT THICKNESS

JACQUES, WHITFORD & ASSOCIATES LIMITED
CONSULTING ENGINEERS

DATE	SCALE	DRAWN BY
16 AUGUST '84	1 : 125,000	V. HUNTLEY

APPROVED BY

DRAWING NO FIGURE 2-2

Bedrock Geology

Stratigraphic Sequence

The coal-bearing rocks of the onshore sector of the coal basin belong to the Morien Group, which, on the basis of the megaflora and spore florule, has been assigned a Westphalian C and D age. The Group reaches its maximum thickness of 1966 m in the Glace Bay and Port Morien Districts, and has been subdivided into three biostratigraphic zones (A to C). These zones, which are based on plant and spore fossils, are transgressive towards the northwest, where the younger zones overstep the older ones.

In the offshore sector additional (post-Morien) coal measures are also present. They comprise spore zone D which has an assemblage indicative of Stephanian age. This zone, which was first encountered in the uppermost seam of the shore section at Point Aconi, was intersected in several offshore boreholes where it ranged in thickness from 183-271 m. It is followed by a sequence of red beds that may extend into the Permain, (Figure 2-3).

The coal-bearing sequence contains thirteen seams that are 0.9 - 4.3 m thick, nine of which occur in spore zones B and C, and three seams are present in zone D. All but the youngest three coals, of which two do not outcrop in the land area, have been mined in the past. The two most productive seams have been the Harbour and Phalen seams, which have been worked extensively in the submarine area adjacent to the coast (Hacquebard, 1983).

Structural Features

It has been suggested that less than 3% of the coal basin occurs onshore and is exposed for mapping. Within the area that has been mined over the past 100 years reasonable structural detail has been determined. Offshore boreholes drilled during the mid to late 1970's have also aided the structural interpretation which extends from the limit of mining to approximately 7 km from the shoreline.

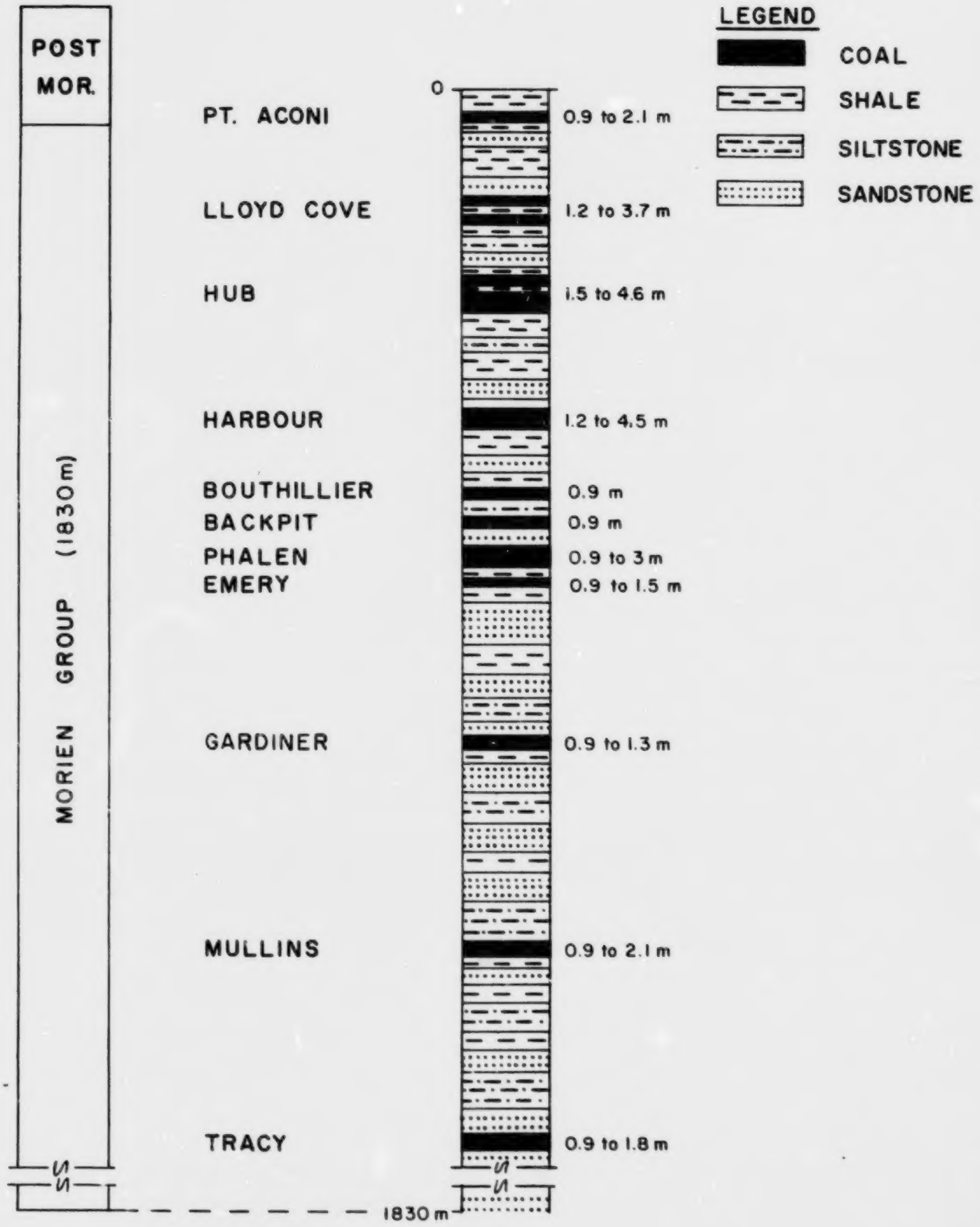

POST MOR.
MORIEN GROUP (1830m)
LEGEND
COAL
SHALE
SILTSTONE
SANDSTONE
0
PT. ACONI
0.9 to 2.1 m
LLOYD COVE
1.2 to 3.7 m
HUB
1.5 to 4.6 m
HARBOUR
1.2 to 4.5 m
BOUTHILLIER
0.9 m
BACKPIT
0.9 m
PHALEN
0.9 to 3 m
EMERY
0.9 to 1.5 m
GARDINER
0.9 to 1.3 m
MULLINS
0.9 to 2.1 m
TRACY
0.9 to 1.8 m
1830 m

FIGURE 2-3 COAL BEARING SEQUENCE OF SYDNEY COALFIELD

(Geological Development and Economic Evaluation of the Sydney Coal Basin, Nova Scotia, by Peter A. Hacquebard, 1983)

As the basin is almost entirely offshore, its structure could be determined only with the aid of shipboard geophysical methods, principally seismic reflection techniques.

The structure of the Sydney Basin is relatively simple and, except for local folding, essentially saucer-shaped with the beds dipping towards the deeper and central parts of the basin. Along its southern boundary, however, a marginal fold belt is present, which is manifested by folding and faulting in the land area of the Sydney coalfield. Here the beds are flexed in open folds that trend easterly to north-easterly with prevailing dips on the flanking beds of 4-15°, reaching 30° in a few instances. This folding was probably initiated by warping during deposition, since in general the coal seams are a little thicker in the synclines than on the anticlines.

Apart from two boundary faults with considerable vertical displacement, located at the western and south-eastern corners of the land area, only minor thrust faulting has been observed in the coalfield. Therefore, the main structures are probably the result of variable subsidence due to sediment load enhanced by differential compaction of the coal measure strata. There are extensive sandstone channels which on occasion cut into the seams and present roof control problems in addition to the potential risk of incendive ignition of methane gas (Hacquebard, 1983).

2.2 Coal Mining Operations in the Sydney Basin

Coal is being produced by three operators in the Sydney Basin. Two strip mines are being operated on Pt. Aconi on the Sydney Main and Upper and Lower Bonar seams by Novaco and T. Brogan and Sons Construction respectively. The larger operations are under ground submarine longwall operations conducted by the Cape Breton Development Corporation (CBDC).

Operating coal mines within the Sydney coalfield are tabulated below. CBDC submarine longwall operations are also shown on Figure 2.1.

Colliery	Location	Seam	Status
Prince Mine	Pt. Aconi	Hub	operating
Novaco	Pt. Aconi	Sydney Main	strip
T. Brogan	Pt. Aconi	Upper & Lower Bonar	strip
Lingan	New Waterford	Harbour	operating
Lingan Phalen	New Waterford	Phalen	developing
No. 26	Glace Bay	Harbour	tem. closed
Donkin	Donkin	Harbour/Phalen	developing

Submarine Coal Mine Operations

All of the underground mining operations in the Sydney coalfield are owned and operated by CBDC a Federal Crown Corporation. Annual coal output is in the order of 2.5 million tonnes with both metallurgical and thermal markets being served.

Three mines - No. 26*, Lingan and Prince all employ the longwall system of extraction. The No. 26 and Lingan mines exploit the Harbour seam while Prince exploits the Hub. All of the present workings are submarine and progressive developments in each of the mines extend out under the ocean floor.

The mine layout is influenced to a large extent by the fact that the resource being exploited is submarine. This means that extraction of the seam can only take place in one direction, giving a one sided mine which in turn means that if the rate of development is to be kept within acceptable limits, then long life faces have to be the rule rather than the exception.

---

*Temporarily closed due to a fire in March, 1984.

At the present time, longwall panels are laid out with a 60 m coal pillar between adjacent units for roadway protection. In the case of advancing faces, the length of each is 215 m while retreat faces are generally 100 m where the cover allows. One exception to the latter is a plan to retreat a 180 m longwall panel on the west side at the Lingan mine.

Other factors which influence the mine layout are the direction and amount of full dip of the seam, the location of the outcrop, and the amount of cover where the main roadways cross beneath the shoreline. Although having the main roadways on or near full dip restricts the design of a man and materials transport system, the disadvantages are far outweighed by the resulting advantages of having the face gate roads at or near level, i.e. on strike (Shield, 1982).

Table 2-1 summarizes the operational aspects of the three producing collieries for 1983 (CBDC, 1983).

Future Plans

The CBDC is actively involved with the location and definition of new coal reserves for development within the Sydney coalfield. Haulage distances and subsequently costs are ever increasing as the submarine longwalls being worked become further and further remote from the shore base bank head. In addition, a higher level of dependence is being placed upon the Cape Breton coal industry as a source of employment for an already economically depressed region. To meet these concerns CBDC has defined several reserve blocks (Figure 2-1), and has accelerated its plans for new mine development.

TABLE 2-1

SUMMARY OF OPERATIONAL ASPECTS OF CBDC'S PRODUCING COLLIERIES

		Colliery	
Statistic	Lingan	Prince	No. 26
Production (1983) million tonnes/ year	1.4	0.75	0.70
Coal Seam/ thickness (m)	Harbour/ 2	Hub 2	Harbour 2
Longwall face length (m)	230	120	230
Pillar Width (m)	65	68	73
Horizontal distance from shore (km)	4	2.4	7
Depth of operations (m)	500	190	700

Although a fire in March 1984, forced the temporary closure of the No. 26 colliery, CBDC is assessing the possibility of reopening the mine, because its permanent closure would have a large negative impact upon the economy of the region. Alternatively, plans for the No. 26 colliery might also include the development of the Harbour Seam, down dip from the existing workings.

Engineering feasibility studies are also being performed for the option of developing the Phalen Seam, in New Waterford, nearby the Lingan Colliery. The 2M Phalen Seam is located 130 m beneath the Harbour seam being mined in the Lingan Colliery.

The evaluation of a major new underground mine at Donkin has been in progress since the late 1970's. Eventual development plans call for 2.0 million tonnes per annum derived from submarine longwall operations.

3.0 SITE CONDITIONS

This section of the report will serve to define the environmental conditions in the area of study, which are considered as potential sources of influence on the proposed project. The primary objective is the identification of optimum conditions for the performance of the study.

Atlantic Canada has an extremely variable and harsh climate as the region is a zone of convergence for cold air masses from the north and warm from the south. Due to these variable conditions, the incidence of favourable weather, for this region of offshore Cape Breton had to be determined. The deployment and servicing of the monitoring instrumentation, ancillary equipment and the retrieval of data could be difficult, if not impossible during inclement weather, especially during the ice season.

Long term (1860- 1982) records available from Environment Canada (Atmospheric Environment Service, 1984) present the frequencies of occurrence for various climatic conditions as well as the related sea state. These records, obtained in a graphical format, and on a seasonal basis when possible, clearly indicate the most advantageous time for the performance of an offshore project. Due to the number of climatic observations, in excess of 7000, the records can be considered significant.

Information on currents, tides and ice conditions have an obvious influence of the deployment of instrumentation and the appropriate seasons for conducting the work.

Socio-economic factors such as the fishing and transportation industries and recreational use of the waters will also have bearing on the conduct of any program.

3.1 Geological Conditions

Geological conditions existing within the Sydney coal- field have been discussed in Section 2. Of prime importance is the regularity in bedrock statigraphy which should provide relatively uniform bedrock conditions on which to found instruments on any given site. Low strata dip angles will also enhance uniform outcrop conditions over reasonable distances.

Sediment thickness determinations have been prepared for CBDC using seismic techniques (Nova Scotia Research Foundation, CBDC, 1979). These surveys, at an accuracy of ± 2m, show variable sediment thickness ranging from 0 m to in excess of 20 m within the study area. The geotechnical characteristics in terms of soil type, strength and mobility are not known. The extent and nature of recent sediments both natural and manmade (mine spoil, dredge spoil etc.) may also be a relevant factor to be considered when siting instrumentation.

Any site which is subsequently identified for monitoring stations would necessarily have to be subjected to a thorough evaluation using standard techniques such as photography, side looking sonar, high resolution seismic and soil borings.

The object of the site survey will be to locate suitable areas without overlying sediments. If the sediments cannot be avoided, then areas of minimal sediment thickness will have to be located and these sediments evaluated.

Seismicity

Published records indicate that seismic activity in the area of the Sydney coalfield is relatively low. There are no known active faults in the area. The seismic zoning maps (National Building Code of Canada, 1980) reflect this low seismic activity.

The peak horizontal acceleration and peak horizontal velocity that can be expected in the area with a probability of exceedance of 10% in 50 years are shown in Figures 3-1 and 3-2 (Heidebrecht, et al. 1983). As shown the peak horizontal acceleration is approximately 0.08 g and the peak horizontal velocity is 0.08 m/s. These values were calculated on the basis of the earthquake events recorded and predicted in the region and adjacent regions. Such events, if they were to occur, should have no significant effect on the operation of instruments used to monitor ground subsidence.

Monitoring of regional seismic events should be part of the overall program as increased subsidence may result from such events. Mining activity in the area will probably also give rise to sudden ground movements, however, such movements are a part of the subsidence process and should be distinguished from regional seismic activity.

3.2 Atmospheric Conditions

Air Temperature

Monthly air temperature readings for the study area are presented in Appendix 3-1. The upper limit ranges from a low of 5°C in February and a high of 20°C in August. The months of June and October have an average temperature of approximately 15°C.

Wind Conditions

Wind records, Appendix 3-2 to Appendix 3-4 present the annual speeds, seasonal frequency of speed by direction and seasonal wind speed exceedance for offshore Cape Breton. The

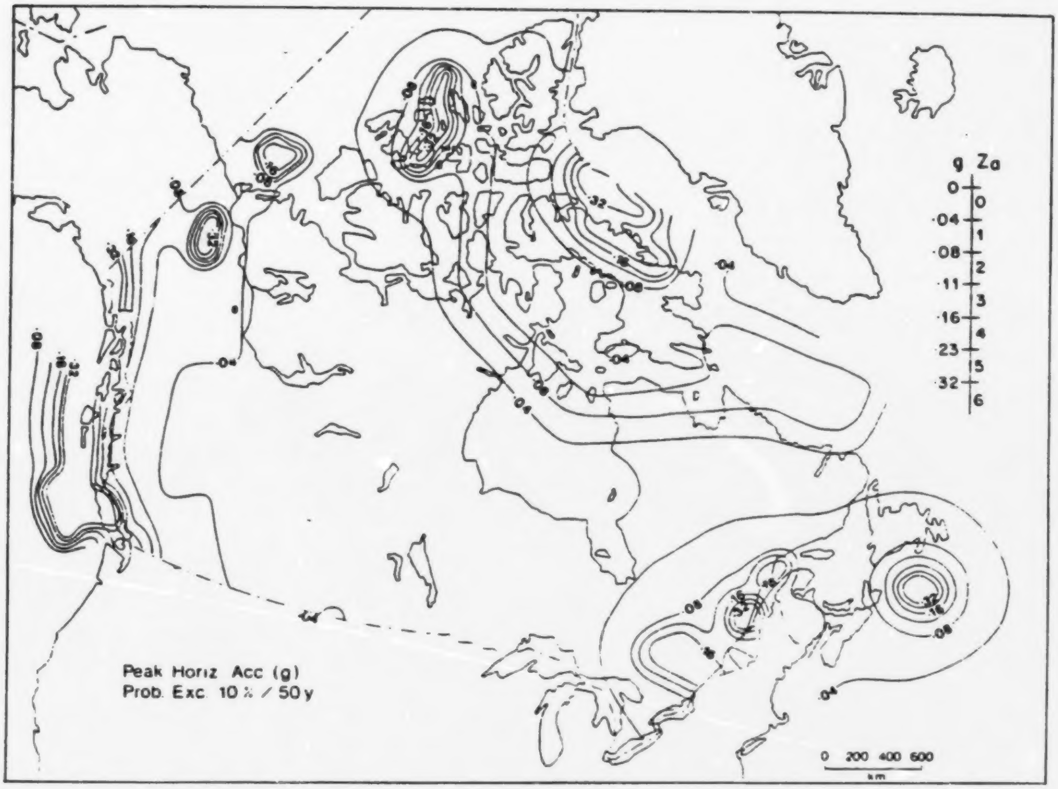

g Za
0 0
.04 1
.08 2
.11 3
.16 4
.23 5
.32 6
Peak Horiz Acc (g)
Prob. Exc. 10% / 50y
0 200 400 600
km

FIGURE 3-1 PEAK HORIZONTAL ACCELERATION WITH A PROBABILITY OF EXCEEDANCE OF 10% IN 50 YEARS.

(Source: Canadian Journal of Civil Engineering, Vol. 10, 1983, by Heidebrecht et al)

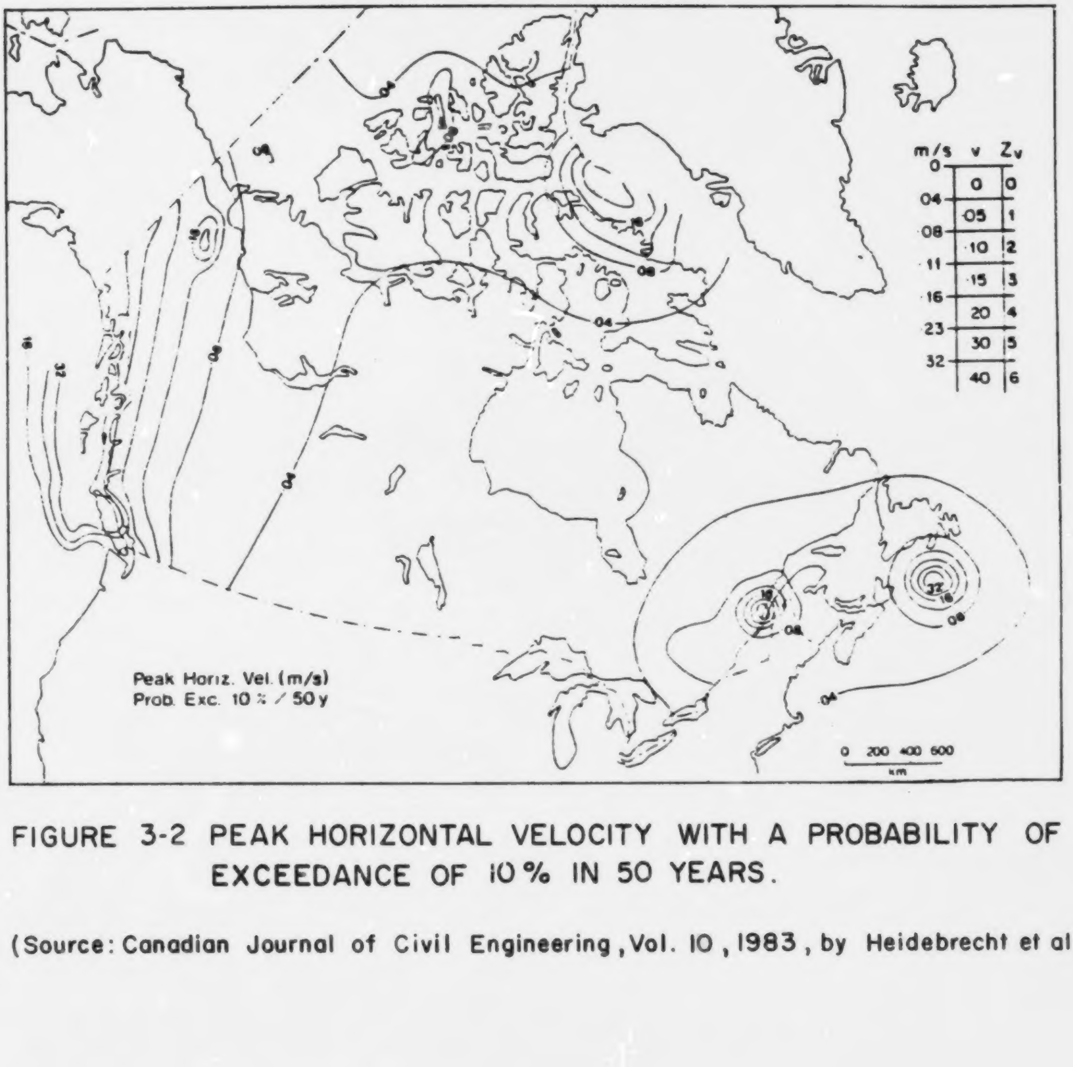

m/s
v
Zv
0
04
·08
·11
·16
·23
32
0
·05
·10
·15
20
30
40
0
1
2
3
4
5
6
04
08
16
32
Peak Horiz. Vel. (m/s)
Prob. Exc. 10 % / 50 y
0 200 400 600
km

FIGURE 3-2 PEAK HORIZONTAL VELOCITY WITH A PROBABILITY OF EXCEEDANCE OF 10% IN 50 YEARS.

(Source: Canadian Journal of Civil Engineering, Vol. 10, 1983, by Heidebrecht et al) maximum wind speed ranges from 40 knots in winter to 25 knots in summer. The summer season has the highest number of calm days with predominant southwest winds while autumn is most windy with prevailing westerly winds.

Wind conditions, such as magnitude, direction, and fetch have direct effect upon the sea state and ice cover, especially during the winter months when stronger winds are more frequent. It is therefore advisable to attempt any offshore endeavors related to this project during calm conditions, such as those encountered during the late spring, summer and early fall seasons.

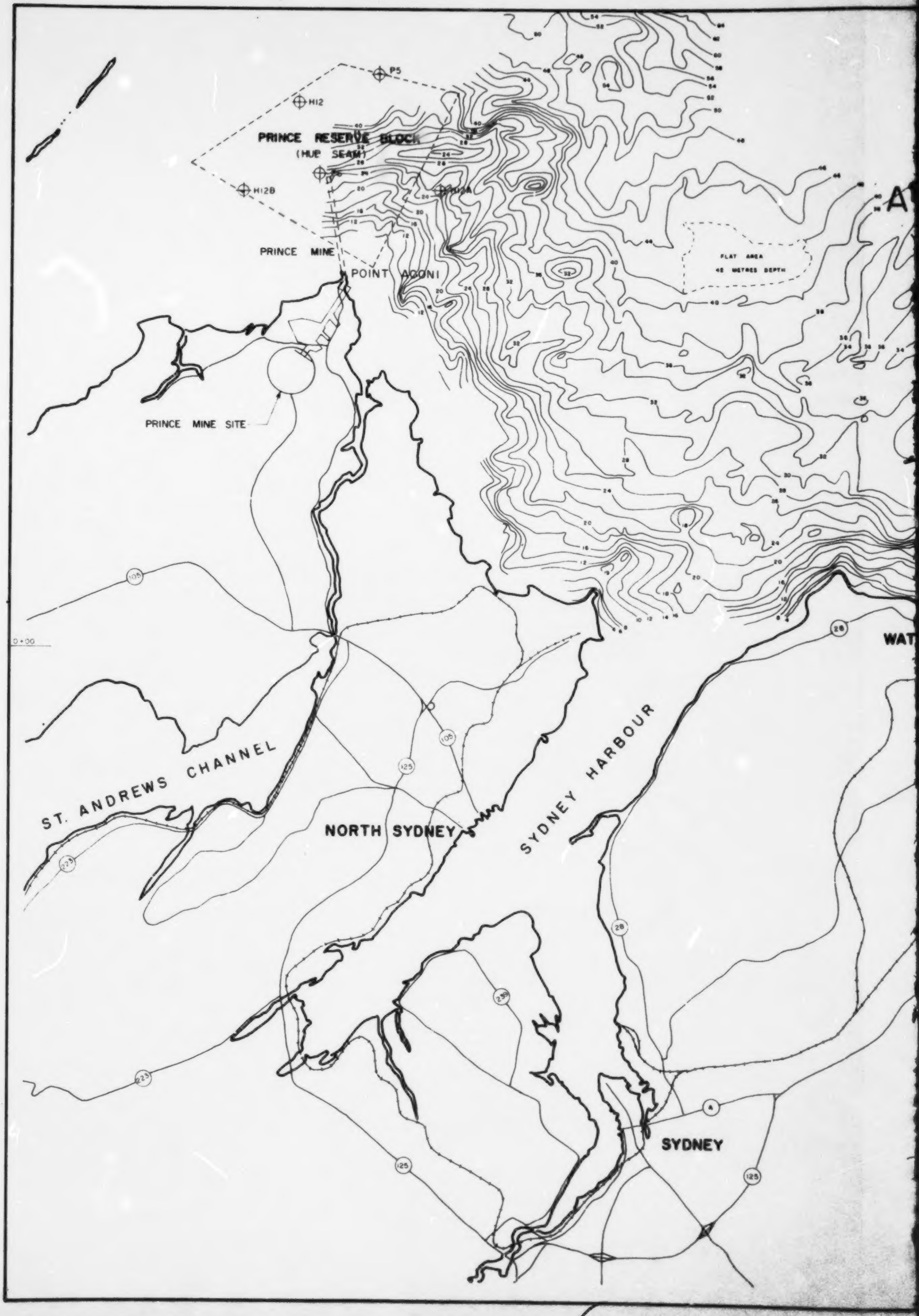
Good visibility is essential for locating the subsidence monitoring stations with optical surveying equipment. As indicated by Appendix 3-5, maximum visibility can be expected during the months of August to November. This four month period would be an optimal time for any surveying assignments if visibilities in excess of 10 km are required.

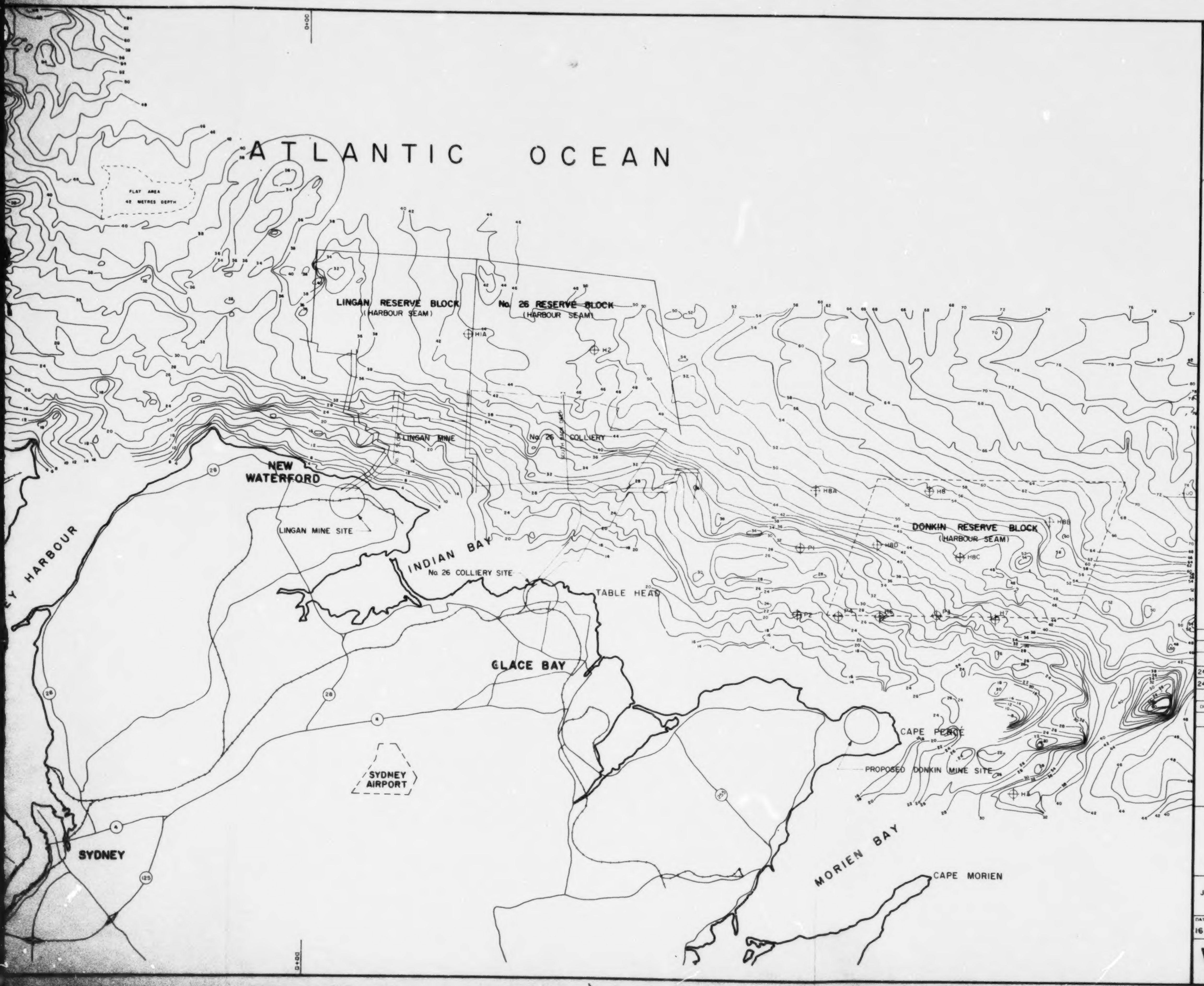
3.3 Bathymetry

The bathymetry of the study area is presented in Figure 3-3, the data for which was obtained from the Nova Scotia Research Foundation seismic data on file with CBDC. The water depths within the various potential study areas is tabulated below.

	Water Depth (m)	
Colliery	Reserve Block	Mining Panel
Prince Mine	8 to 40+ m	25 m
Lingan	34 to 44 m	34 m
Lingan Phalen	0 to 35 m	NA
No. 26	30 to 50 m	45 m
Donkin	28 to 68 m	30 m

Instrumentation and systems that are selected for use must be compatible with a minimum specification for at least 35 m of water head.


PRINCE RESERVE BLOCK
(HUB SEAM)
P5
H12
H12B
H13A
PRINCE MINE
POINT ACONI
PRINCE MINE SITE
FLAT AREA
42 METRES DEPTH
0+00
ST. ANDREWS CHANNEL
NORTH SYDNEY
SYDNEY HARBOUR
SYDNEY
105
125
223
239
28
4
A
WAT


ATLANTIC OCEAN
FLAT AREA
42 METRES DEPTH
LINGAN RESERVE BLOCK
(HARBOUR SEAM)
No. 26 RESERVE BLOCK
(HARBOUR SEAM)
H1A
H2
LINGAN MINE
No. 26 COLLIERY
NEW WATERFORD
LINGAN MINE SITE
INDIAN BAY
No. 26 COLLIERY SITE
TABLE HEAD
H8A
H8
H8B
H8D
H8C
P1
P2
P3
H7
DONKIN RESERVE BLOCK
(HARBOUR SEAM)
GLACE BAY
CAPE PERCE
PROPOSED DONKIN MINE SITE
SYDNEY AIRPORT
SYDNEY
MORIEN BAY
CAPE MORIEN
HARBOUR
0+00
28
4
125
255

LEGEND

⊕	C B D C EXPLORATION BOREHOLE.
0+00	C B D C MINE GRID
—36—	WATER DEPTH IN METRES (NO TIDAL CORRECTION)

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No.	DETAILS	DATE
	REVISIONS	
2457-1	Nova Scotia Research Foundation	AUG./79
2457-2	Nova Scotia Research Foundation	AUG./79
320-P	Cape Breton Development Corporation	NOV /79
DRWG. NO.	DESCRIPTION	DATE
	REFERENCES	

ENERGY, MINES & RESOURCES

SUBMARINE SUBSIDENCE

SYDNEY, NOVA SCOTIA

BATHYMETRY

JACQUES, WHITFORD & ASSOCIATES LIMITED
CONSULTING ENGINEERS

DATE	SCALE	DRAWN BY
16 AUGUST '84	1:125,000	V. HUNTLEY

APPROVED BY

DRAWING NO. FIGURE 3-3

3.4 Seawater Properties and Sea State

Seawaters in the study area are derived from the Gulf of St. Lawrence and form the eastern edge of the Cape Breton current flowing southward through the Cabot Strait. Water stratification and hence properties (temperature, density, salinity) normally occur in three layers.

- wind mixed or surface layer of almost uniform properties
- intermediate layer of rapid changing properties
- deep layer of gradual changing properties

Specific depths of each layer must be determined in the area of concern for those properties that will effect instrumentation and or sensors. A more detailed discussion of these properties may be found in Section 6.

The data presented has generally been drawn from public sources and represents average values for the area. The data should be confirmed with site specific information prior to the conduct of any study.

Water Temperature

A typical annual sea surface temperature curve, Appendix 3-6, illustrates the summer peak and winter low of 20°C (August) and 0°C (March) respectively. Water temperature is depth dependent; the summer high at the -40 m level is approximately 5°C. As the velocity of sound varies with water temperature, it will be necessary to determine the site specific water temperature when performing acoustic surveys.

Water Salinity

Salinity values on a monthly basis for the study area are presented in Appendix 3-7. These values generally range between 30-31 parts per thousand except for a minimum in November caused by the passage of the spring freshwater runoff from the St. Lawrence River and Great Lakes System. This minimum is depth dependent and occurs only in the top 15 to 20 m.

Currents and Tides

Information regarding currents and tides is available for the study region from the Canadian Tide and Current Tables Volume 1 (Fisheries and Oceans Canada, 1984). The nearest current reference area is for Great Bras D'or and indicates when the current is at its maximum but not its magnitude. Hydrographic charts (Canadian Hydrographic Service, 1984) do not indicate any water currents for the region. It may therefore be necessary to monitor the (site specific) currents prior to locating the subsidence monitoring instrumentation.

The tidal variation for the study area is presented in Figure 3-4. The graph represents the variations between monthly low and high tide levels and shows that the range is in the order of 1.25 m. There is insignificant variation with season.

Wave Heights

Observations of combined wave height, period and direction in the region for montioring were obtained from Environment Canada's Marine Statistics Package (MAST) on a seasonal basis. Wave observations are generally reported as sea height, swell height, period and direction. A combined wave height is determined by:

$$H\text{ combined} = \left(H^2\text{ sea} + H^2\text{ swell}\right)^{1/2}$$

and is considered equivalent to the significant wave height. A general overview of the wave climate is provided by Appendix 3-8, the monthly distribution of wave heights. A trend of higher waves in winter than in summer can be seen; with the most frequent directions indicated at the top of the plot. Rose diagrams of wave height giving the frequency of the combined wave height by direction on a seasonal basis are illustrated in Appendix 3-9. The predominant waves for the winter, spring, summer and fall seasons are from the west, south, south-southwest and southwest respectively. The winter season has the lowest precentage of calm conditions.

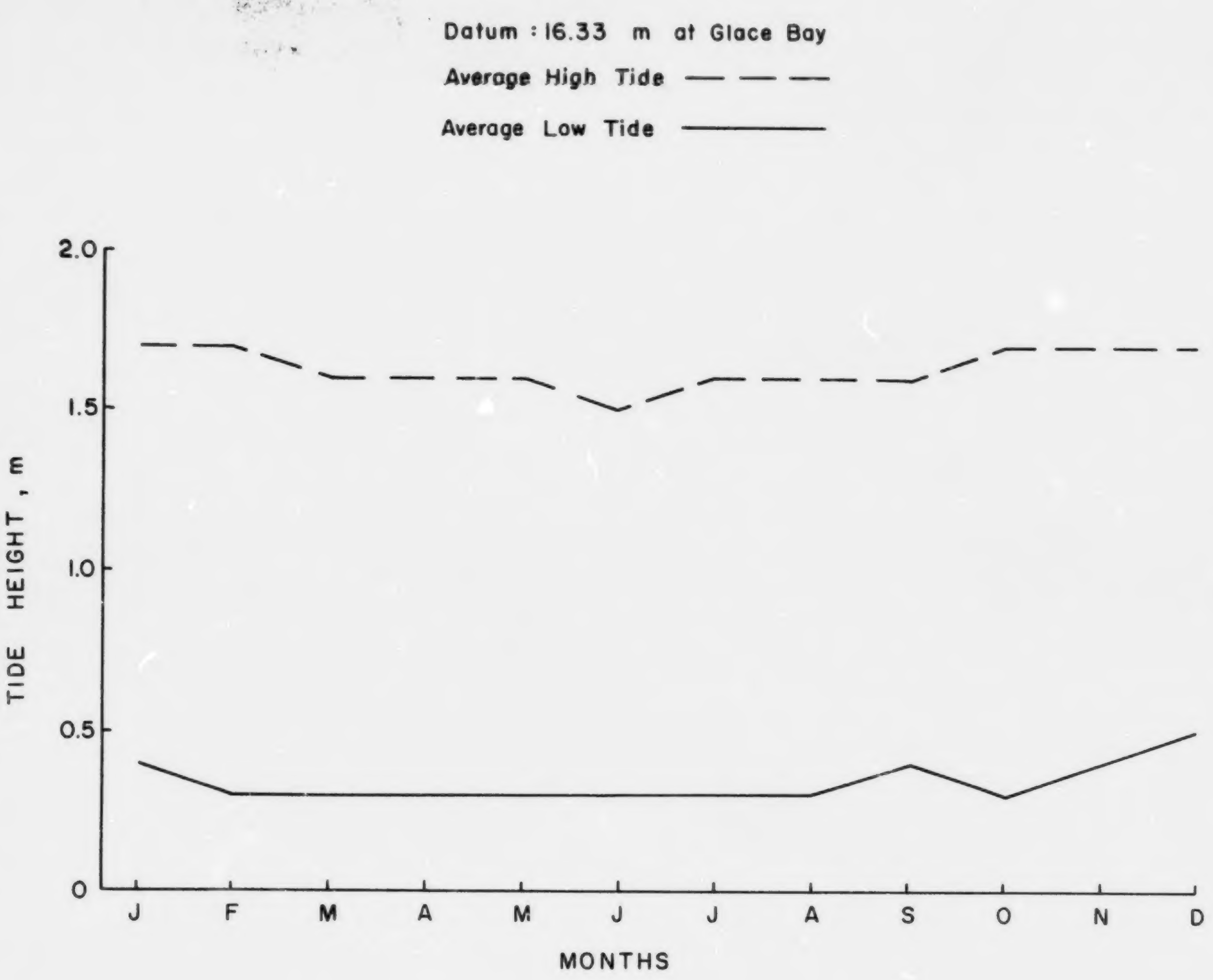


FIGURE 3-4 ANNUAL RANGES OF TIDE HEIGHTS FOR NORTH SYDNEY

(Source: Canadian Tide and Current Tables, 1984, Vol. I)

Histograms of combined wave period by percent are presented in Appendix 3-10. The majority of waves in the study area have periods of 5 seconds or less, indicating relatively small waves. The frequency of higher period waves is greater during the winter months. Appendix 3-11 presents combined wave height exceedance diagrams which reveal the percentage of time combined waves above a specified height can be expected and could be used to predict the likelihood of occurrence of a critical wave height. The winter and spring seasons are clearly the times when the greatest combined wave heights can be expected to occur.

Ice Conditions

A large part of Canada's east coast, including that of Cape Breton, experiences the seasonal effects of ice. Ice begins to form to the north of Labrador in November/December and moves slowly south at about 16 kilometers per day, reaching the Grand Banks in February/March, and often extends as far south as Latitude 46°N. The natural thickness is in the order of a meter, but wave action creates ridges and hummocks which often generate thicknesses of 3 to 5 meters. These can persist for quite some time, even after they reach the Grand Banks. Southern progression is maximized normally around April/May, when the winds tend to become westerly and the ice is driven eastward into warmer waters and melts, starting a northward retreat of the pack. It clears the Belle Isle Strait about the end of May in most years and the northern Labrador coast about the third or fourth week in July.

Seasonal ice of local origin is found in the Gulf of St. Lawrence and Cabot Strait, beginning in December and reaches its maximum extent in late February. The ice stream departs the Gulf and spreads south and southwest toward Sable Island, frequently engulfing the northeast coast of Cape Breton. When the fields have their greatest extension, the ice spreads east-northeastward towards the southern shore of Newfoundland, though seldom actually reaches the coast.

Figures 3-5 and 3-6 show the average winter and spring ice regimes for Atlantic Canada which are the peak ice seasons for the region. The deployment of subsidence monitoring instrumentation and ancillary equipment such as buoy markers would be difficult during these periods (Wilson et al, 1984).

3.5 Socio-Economic Considerations

The Fishery

The commercial fishing industry is a major contributor to the economy of Cape Breton. The fishery is diverse and a variety of methods are utilized to land pelagic and groundfish as well as lobster and crab. Groundfish, species sush as cod, haddock and flatfish which live and feed on or near the seabottom, are caught usually with otter trawls, baited hooks (longlines) and gill nets or occasionally with jigs. Pelagic species, such as herring, mackeral, gasperau and salmon live and feed near the water surface and are traditionally landed with gill nets or seines, although jigs are frequently used. Lobster and crab, both bottom scavengers, are caught with either wooden or metal framed traps. Scallops are landed commercially with draggers.

The area to be monitored for submarine mine subsidence is contained within Department of Fisheries and Oceans (DFO) districts 4VN,6B and 4. District 4VN defines the region fished for ground and pelagic species while districts 6B and 4 are lobster and crab fishery zones respectively. The ground and pelagic fisheries do not have fixed duration seasons but operate on a quota system which is usually filled between April and December. DFO pesonnel suggest there is usually a year round fleet harvesting various groundfish and pelagic species. The lobster season for DFO district 6B extends from May 15 to July 16 while the crab fishery season, for District 4 extends from July 22 to September 15. Minor scallop fishery takes place between May and November.

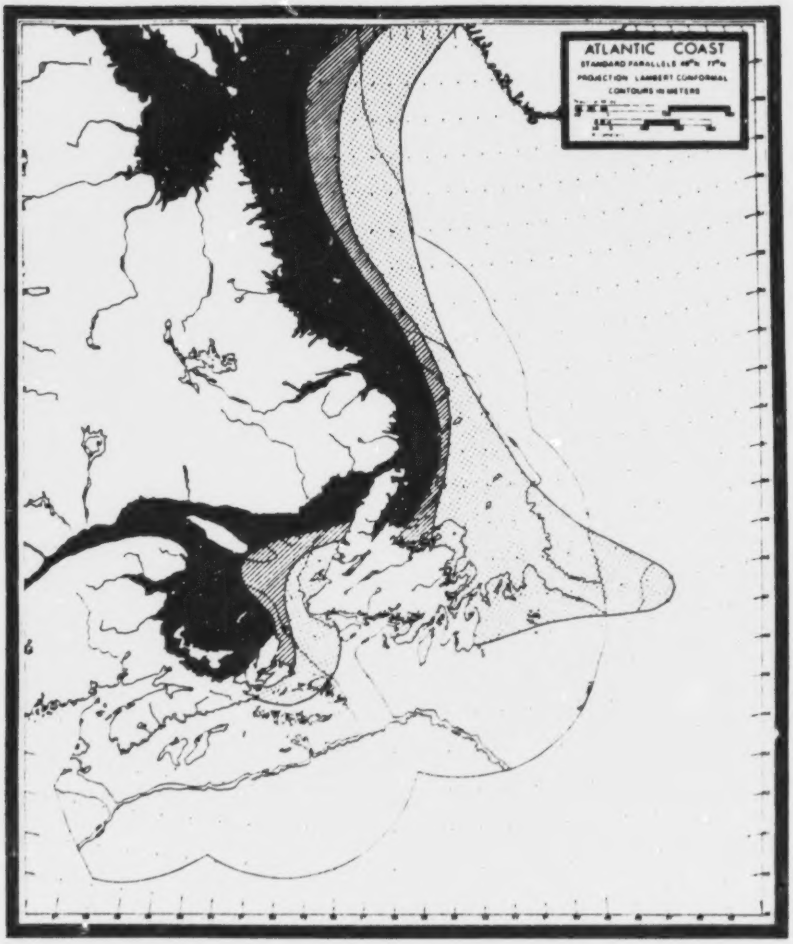

ATLANTIC COAST
STANDARD PARALLELS
PROJECTION LAMBERT CONFORMAL
CONTOURS IN METERS

Figure 3-5 Average winter ice conditions: close pack ice, solid black; open pack ice, diagonal; maximum extent of all ice, stippled .

(Source : Health of the Northwest Atlantic , Environment Canada)

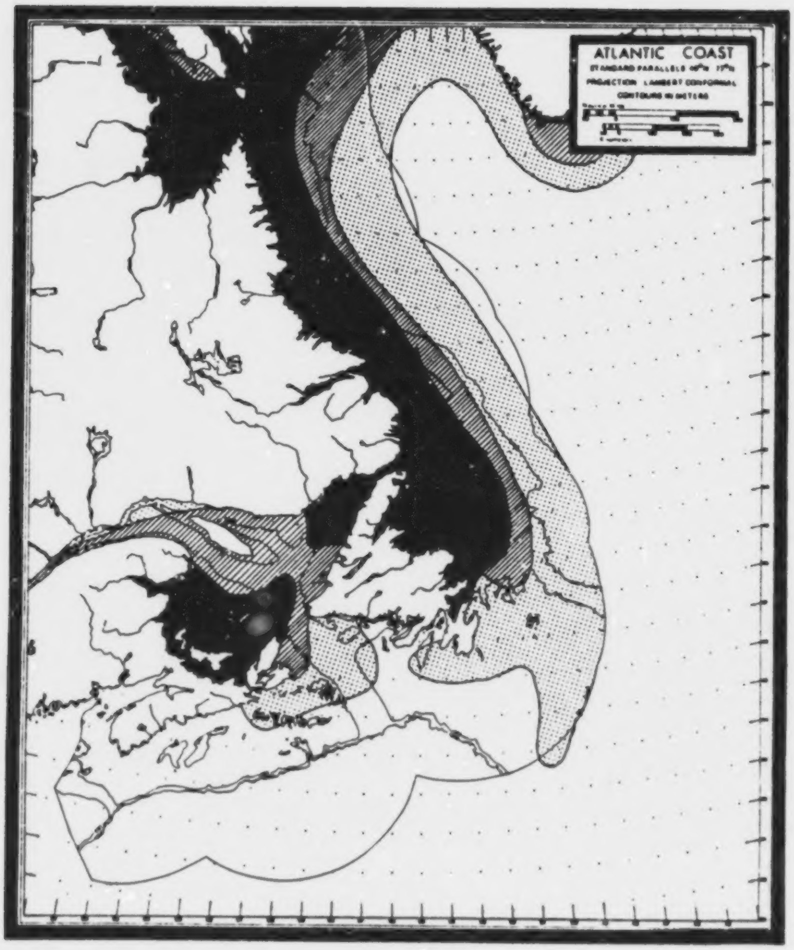

ATLANTIC COAST
STANDARD PARALLELS
PROJECTION LAMBERT CONFORMAL
CONTOURS IN METERS

Figure 3-6 Average spring ice conditions: close pack ice, solid black; open pack ice, diagonal; maximum extent of all ice, stippled .

(Source: Health of the Northwest Atlantic , Environment Canada)

The pelagic fishery should not interfere with the deployed subsidence monitoring system as only the upper water levels are fished and the gear used is static. The traps used for catching lobster and crab are also static and therefore should not pose any hazard to the positioned monitoring hardware. The zones intended for subsidence data accumulation should avoid traditional ground fishery areas as the fishing equipment used is generally dynamic and tends to disturb the bottom. DFO regulations prevent ships greater than 20 m using otter trawls from fishing within 20 km from any point of land, however smaller ships are permitted to use similar equipment for fishing inside the 20 km limit. Areas dragged for scallops should also be avoided as the equipment used for this harvesting seriously disturbs the seafloor.

Table 3-1 presents data on fishery landings and number of fishermen employed in the area. Figure 3-7 is based on data provided by DFO and shows the nominal limits of the various fishery activities. The figure suggests that if a program is initiated at Prince Mine the major concern will be scallop dragging operations nearby Pt. Aconi. It may be necessary to make arrangements with DFO to restrict specific areas from fishing for the duration of the subsidence monitoring exercise.

TABLE 3-1

1983 FISHERY SUMMARY

Statistical District 6B

Number of Licensed Fishermen - 407 Number of Vessels - 298

Total Groundfish Landings	19,960 metric tonne
Total Pelagic Landings	3,964 metric tonne
Total Crab Landings	21 metric tonne
Total Lobster Landings	298 metric tonne

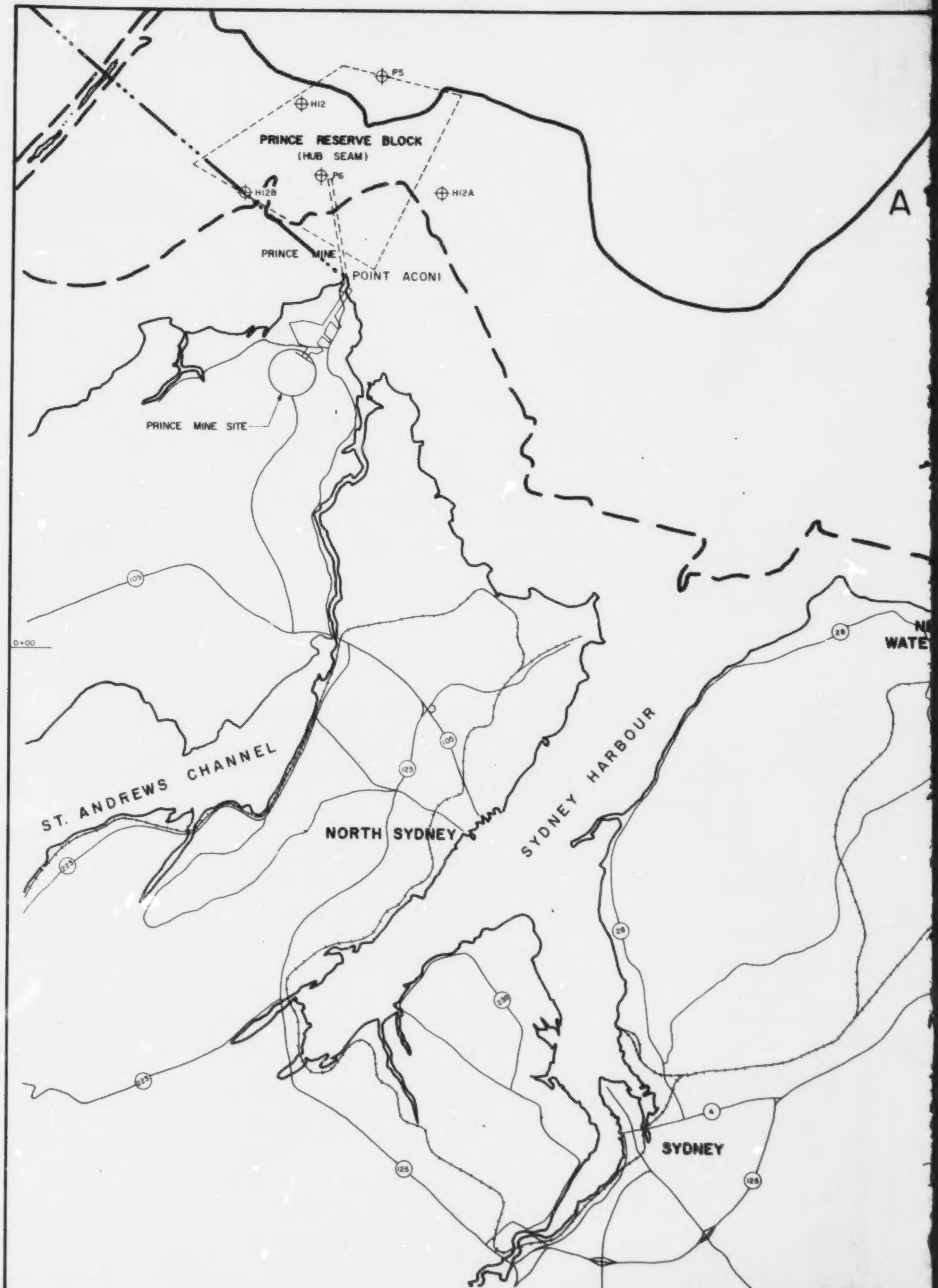
Statistical District 7

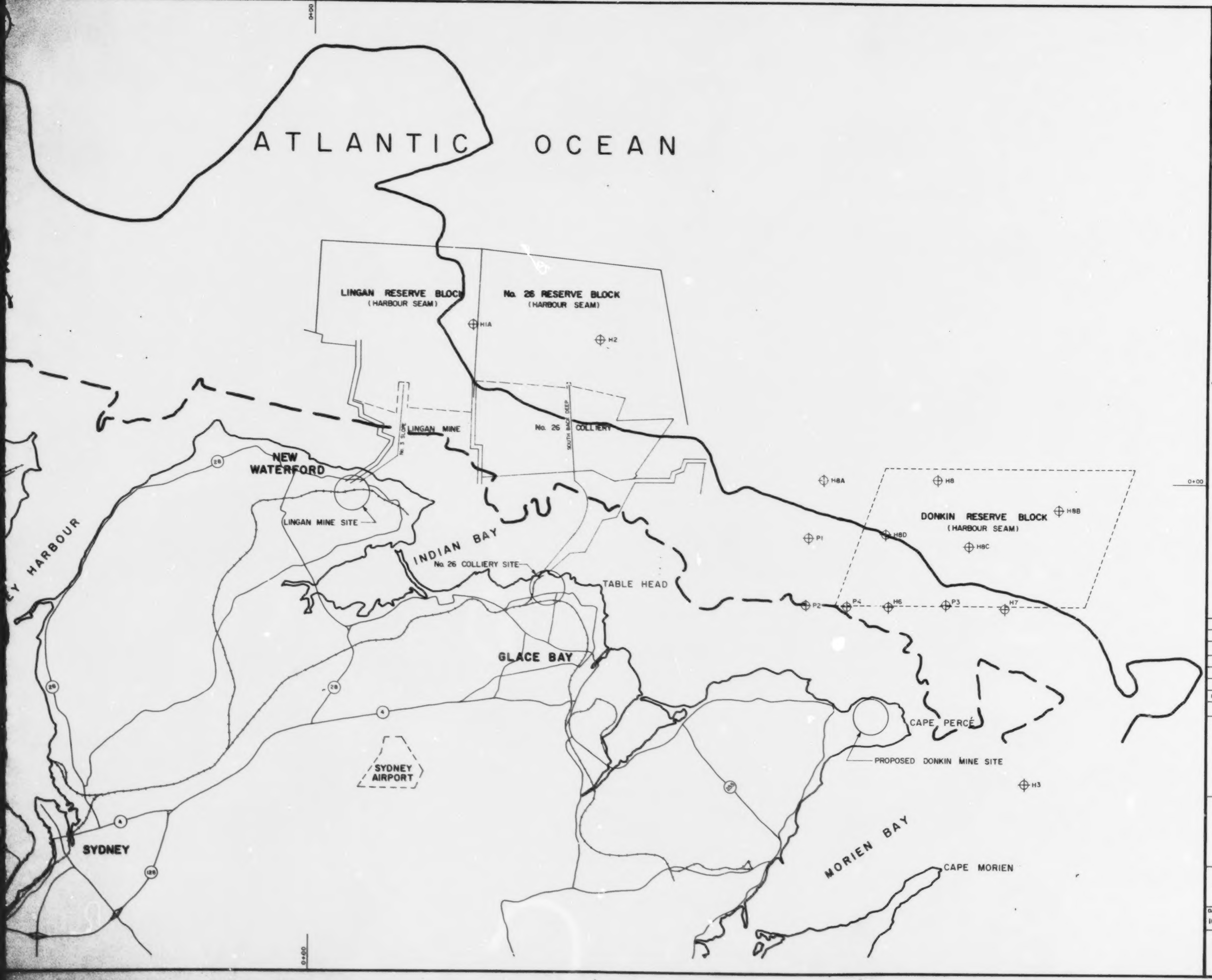
Number of Licensed Fishermen - 558 Number of Vessels - 257

Total Groundfish Landings	20,989 metric tonne
Total Pelagic Landings	346 metric tonne
Total Crab Landings	103 metric tonne
Total Lobster Landings	674 metric tonne

Source: DFO, Sydney, Nova Scotia

NOTE: The districts used are defined for the lobster fishery.


P5
H12
PRINCE RESERVE BLOCK
(HUB SEAM)
P6
H12B
H12A
A
PRINCE MINE
POINT ACONI
PRINCE MINE SITE
105
0+00
NE
WATE
28
ST. ANDREWS CHANNEL
105
125
SYDNEY HARBOUR
NORTH SYDNEY
225
28
239
225
4
SYDNEY
125
128



0+00
ATLANTIC OCEAN
LINGAN RESERVE BLOCK
(HARBOUR SEAM)
No. 26 RESERVE BLOCK
(HARBOUR SEAM)
H1A
H2
No. 3 SLOPE
LINGAN MINE
SOUTH BACK DEEP
No. 26 COLLIERY
NEW WATERFORD
28
LINGAN MINE SITE
INDIAN BAY
No. 26 COLLIERY SITE
TABLE HEAD
GLACE BAY
EY HARBOUR
H8A
H8
H8B
DONKIN RESERVE BLOCK
(HARBOUR SEAM)
H8D
H8C
P1
P2
P4
H6
P3
H7
0+00
28
4
SYDNEY AIRPORT
CAPE PERCÉ
PROPOSED DONKIN MINE SITE
H3
MORIEN BAY
CAPE MORIEN
SYDNEY
126
0+00

LEGEND

⊕ C.B.D.C. EXPLORATION BOREHOLE

0+00 C.B.D.C. MINE GRID

━━ NORTHERN LIMIT OF INSHORE LOBSTER FISHERY

— — SOUTHERN LIMIT OF GROUND FISHERY / NORTHERN LIMIT OF PELAGIC FISHERY

—··— NORTHERN LIMIT OF SCALLOP FISHERY

THIS DRAWING FORMS PART OF JACQUES, WHITFORD AND ASSOCIATES REPORT No. M1255 AND SHOULD BE READ IN CONJUNCTION WITH THE REPORT.

NO	DETAILS	DATE
REVISIONS		
320-P	Cape Breton Development Corporation	NOV. / 79
DRWG NO	DESCRIPTION	DATE
REFERENCES		

ENERGY, MINES & RESOURCES

SUBMARINE SUBSIDENCE

SYDNEY, NOVA SCOTIA

NOMINAL LIMITS OF THE VARIOUS FISHERY ACTIVITIES

JACQUES, WHITFORD & ASSOCIATES LIMITED
CONSULTING ENGINEERS

DATE	SCALE	DRAWN BY
16 AUGUST '84	1:125,000	V.H. / R.M.

APPROVED BY

DRAWING NO FIGURE 3-7

RESTRICTED AREAS

According to hydrographic chart L/C 4367, published by the Department of Fisheries and Oceans Hydrographic Service, there are presently no areas of restricted access in the area proposed for subsidence monitoring.

Under the provisions of the Canada Fisheries Act, the Minister of Fisheries can prohibit access to specific areas for the purpose of fishing. Should it become necessary, petition can be made to the Minister requesting such a restriction to the areas in which subsidence monitoring hardware has been deployed. This measure should be used as a last resort only because it may not be popular with the local fishermen. Although application must be made to the Minister of Fisheries, the local fishermen should also be informed prior to proceeding.

MARINE TRANSPORTATION INDUSTRY

The port of Sydney, the major industrial centre of Cape Breton, supports a regular flow of shipping traffic throughout the year, with facilities to accommodate a variety of cargos and passengers.

Canadian National, sailing from North Sydney, has ferries navigating the Cabot Strait between Nova Scotia and Newfoundland. These crossings are scheduled daily and have traditional routes of travel.

As well as receiving a variety of inbound cargos, Sydney Harbour also provides facilities for exporting consignments of coal and steel products. The departures and destinations of these products are varied and therefore the scheduling and routing of the vessels is not fixed.

An examination of the hydrographic chart shows that Sydney and the nearby harbours, Alder Point and Glace Bay, do not have distinct shipping lanes assigned. Harbour access is controlled by navigational buoys only. Shipping may therefore navigate any waters of sufficient depth and could traverse potential monitoring areas particularly from Lingan Colliery eastward to Donkin.

There is a high potential for damage to floating equipment by surface vessels. It may be necessary to obtain authorization from the Ministry of Transport to restrict access to the monitoring site. This may be accomplished via notice to Mariners for short term deployment of scientific packages.

It is recommended that any instrumentation used in association with the subsidence monitoring program be deployed in areas outside the regularly charted waterways; both for the safety of the equipment and the traversing vessels.

RECREATIONAL AREAS

The Cape Breton community is traditionally oriented towards the sea, therefore there are many pleasure boats used in the area. These boats, used mainly for pleasure sailing, fishing, water skiing, etc., should not affect the subsidence monitoring system after it is deployed. However, favorite haunts of these weekend sailors should be avoided because buoys associated with the instrumentation may attract the curious.

SECTION 4.0 - GROUND MOVEMENT, LAND BASED INSTRUMENTATION AND DESIGN CRITERIA ASPECTS OF SEABED MONITORING OF MINING SUBSIDENCE - AMCL

4.1 INTRODUCTION

Aims

As longwall mining develops under the Atlantic Ocean off Cape Breton Island, Nova Scotia, the effect of subsidence of the seabed becomes a critical design parameter, often restricting the amount of coal to be extracted. The object of this study is to produce "a summary compilation and evaluation of methods of collecting seafloor and/or seafloor/bedrock data on subsidence over longwall coal mines".

Such methods must be capable of obtaining precise measurements at fixed points on the seabed in the area above the mine workings for periods in excess of one year. To this end, it is first necessary to review:-

(i) those ground movements, caused by mining, which are to be measured;

(ii) the current land-based systems of measurement and their applicability to the undersea environment.

Following such a review the outline design criteria (from a mining subsidence viewpoint) for an undersea monitoring scheme can then be summarised.

The objectives of the specific measurement systems to be adopted must of course be compatible with the objectives of the subsidence monitoring program as a whole. For example, land based measurement systems have been developed in Europe and the US over the last four decades to enable monitoring programs carried out in those coalfields to ascertain the basic characteristics of ground movement. These include:-

(i) the relationship, magnitude and extent of surface movements,

(ii) the relationship between vertical and horizontal movements,

(iii) the influence of time,

(iv) the relationship between movement and damage (mainly to man-made structures).

The knowledge so gained has generally been used to develop prediction models to precalculate surface movements and hence minimise surface damage. The stability of structures has mainly been achieved by applying the results to improve design of mine workings whilst ensuring good recovery of increasingly valuable coal reserves.

When considering the design of a new and specific subsidence monitoring program and the instrumentation requirements in a coalfield with limited data, the overall objectives must be clarified at the outset. The magnitude and extent of the monitoring system can then be determined. For example, if the sole purpose is to improve the subsidence prediction procedures, then surface measurements alone may suffice. However, if, as in the case of subsea workings, it is important to increase understanding of the behaviour of the near-surface strata mass as a whole then the monitoring system should be extended to include measurements of the rock mass behaviour throughout the zone influenced by mining. Instrumentation requirements would then encompass geotechnical techniques (reviewed in Sections 5 and 6). The latter could be used within underground galleries, in boreholes drilled from the surface, or in boreholes drilled from underground galleries.

It is understood that in this study the objective is primarily to obtain first hand submarine subsidence data, which will be used to check existing design procedures and ultimately to revise them.

Within this overall objective, AMCL's section of the study covers:-

(i) the background movements to be measured both in general and for the Sydney Coalfield,

(ii) land-based instrumentation systems,

(iii) a summary of the design criteria (from a mining viewpoint) for an undersea subsidence monitoring system,

(iv) underground instrumentation approach.

4.2 - GROUND MOVEMENTS FROM LONGWALL MINING

Mining Subsidence

In Europe, and particularly in the United Kingdom, where the longwall mining system has dominated for many years, numerous ground control studies of coal mining areas have been carried out over the last four decades. Many of these have included specific subsidence monitoring studies. Analysis of the resultant large data base has led to a better understanding of the rock mass deformation as a whole above mine workings and hence of subsidence deformation of the ground surface (Refs 4.101 and 4.102). A summary of the current understanding of ground movement over longwall workings is presented below.

As a void is created by the mine workings, the overlying strata move to fill the void, acting under the force of gravity (and the effects of any inherent tectonic forces). The surface subsidence arising from these movements depends principally upon the mining and strata conditions, varying from intense deformation and cracking to barely discernable movement. The normal case is characterized by a relatively continuous deformation of the surface inducing both vertical and horizontal displacement of surface points. The resultant depression is basin-shaped (Figure 4.1) or, if examined in cross-section, trough-shaped, hence the term "subsidence trough" (Figure 4.2).

Permanent Ground Deformation

Characteristics of Displacement

The characteristics of a typical subsidence trough can be described with reference to a single, rectangular longwall extraction area in a flat seam. When working ceases, the final subsidence trough remains as a permanent feature in the ground, until affected by any subsequent mine working or other activity in the area. In the case of a single extraction area in a flat seam, the final state of surface deformation is characterized by the following features referred to in Figures 4.1, 4.2 and 4.3:-

(i) Vertical displacement or subsidence of surface points forming a subsidence trough, which normally extends, in plan view, beyond the edges of the mined area in all directions. The magnitude depends principally upon the depth and size of excavation (width, length and extracted height).

(ii) Horizontal displacement which accompanies the vertical displacement, and which is appreciably larger than could be expected from ground curvature due to the subsidence alone. Its magnitude and direction are approximately proportional to the slope of the subsidence profiles.

(iii) Regular "trough" shape, centrally and symmetrically positioned (if the extraction area has a geometrically regular shape), develops with the maximum subsidence over the area's center (normally to the dip of the seam), see Figure 4.2.

Derivatives of Displacement

The derivatives of the displacement curves are of special interest as they influence the occurrence of surface damage. They are:-

(i) the slope of subsidence profiles,

(ii) the curvature of subsidence profiles, and

(iii) the strains - extensions and compressions - which result from the horizontal displacement.

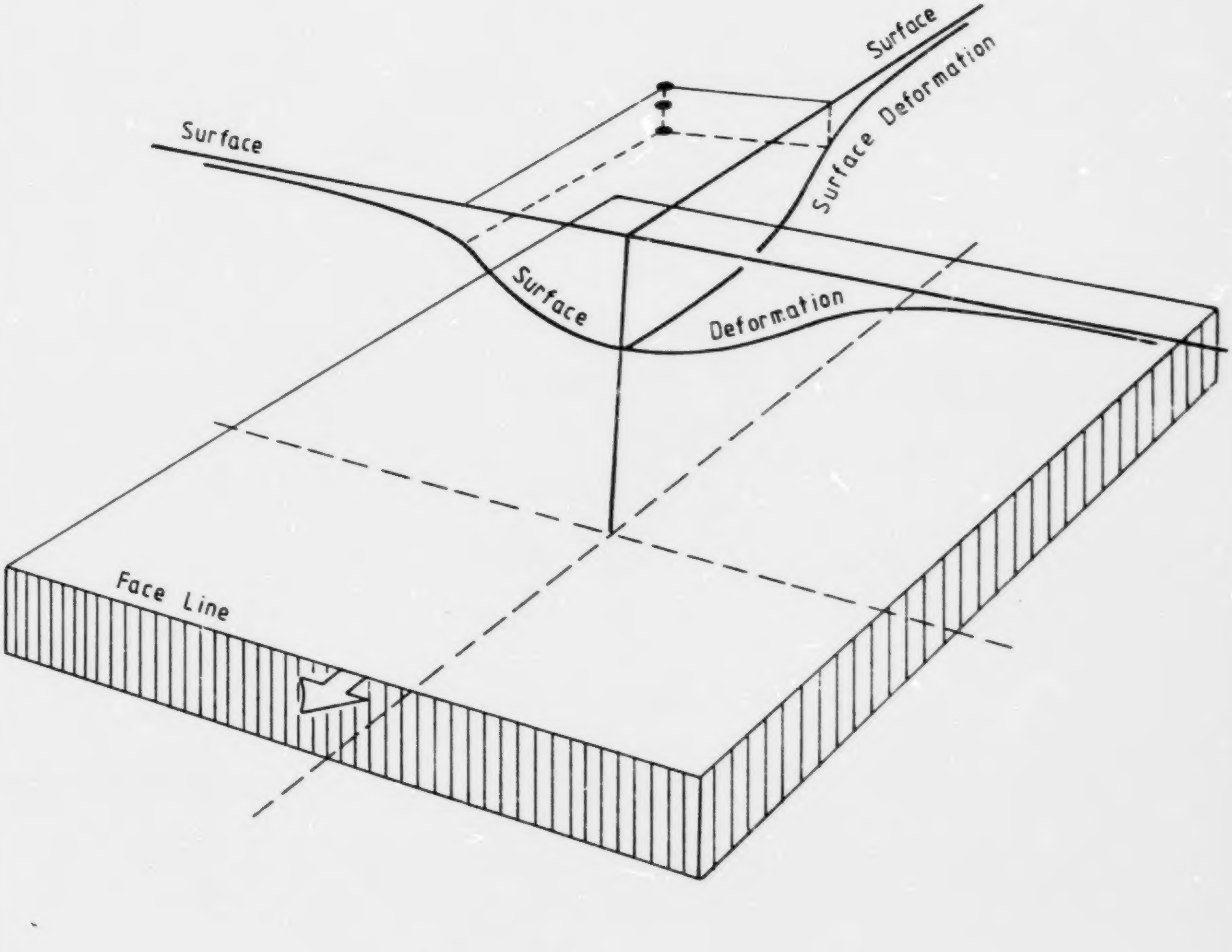
The derivatives are described by the magnitude and direction of the displacements and are often derived from the measured values of these.

Critical Subsidence

The vertical displacement component, the subsidence, has a definite upper limit which depends on the seam thickness and is an important basis of

Figure 4.1

THREE DIMENSIONAL ILLUSTRATION OF MINING SUBSIDENCE


Surface
Surface Deformation
Surface
Surface Deformation
Face Line

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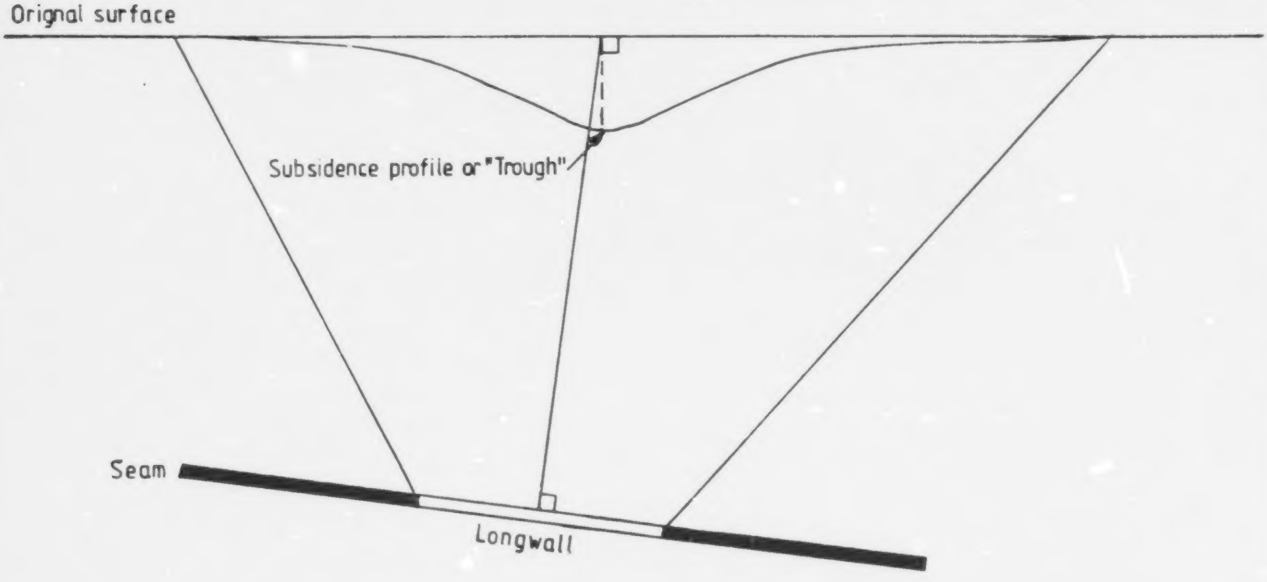
EFFECT OF SEAM DIP ON SURFACE SUBSIDENCE TROUGH


Orignal surface
Subsidence profile or "Trough"
Seam
Longwall

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Traced by...... T N	Drg No 15/0193/3/

calculation. This limit value is referred to as "maximum possible subsidence" or "full subsidence". It only occurs if the extraction area has a certain minimum size, the so-called "critical area". The critical area produces full subsidence at a single surface point. Areas that produce full subsidence at more points are "supercritical"; areas that produce partial subsidence are "subcritical". Figure 4.3 illustrates these three extraction cases. If the length of the extraction area perpendicular to the plane of the figure is large enough, a state of approximately plane deformation exists in the central region of the trough. The main features are as follows.

In case of the critical area (Figure 4.3), the maximum subsidence at the centre is associated with zero curvature and zero strain. The horizontal displacment reaches a maximum possible value in the region over the ribsides.

The maximum subsidence over a subcritical area depends on the size of that area in relation to its depth. Considering the two-dimensional case, other quantities being equal, this means that all extraction areas having the same width-to-depth ratio produce the same maximum subsidence. This equivalance is illustrated in Figure 4.4; any extraction area determined by an isosceles triangle would cause the same subsidence at the top of the triangle, that is, at the surface point P over the extraction centre. In addition, depth alone also has an influential effect.

Transitional Ground Deformation

It is important to note that the subsidence trough is progressively formed as a longwall panel is mined, (see Figure 4.1). These movements are dynamic as the subsidence development curve moves through the ground above the working face. The ground deforms in one three-dimensional field of movement, such that arbitrarily to divide this into two components (say transverse and longitudinal), purely to simplify observation procedures, could lead to a misleading and partial picture of the whole.

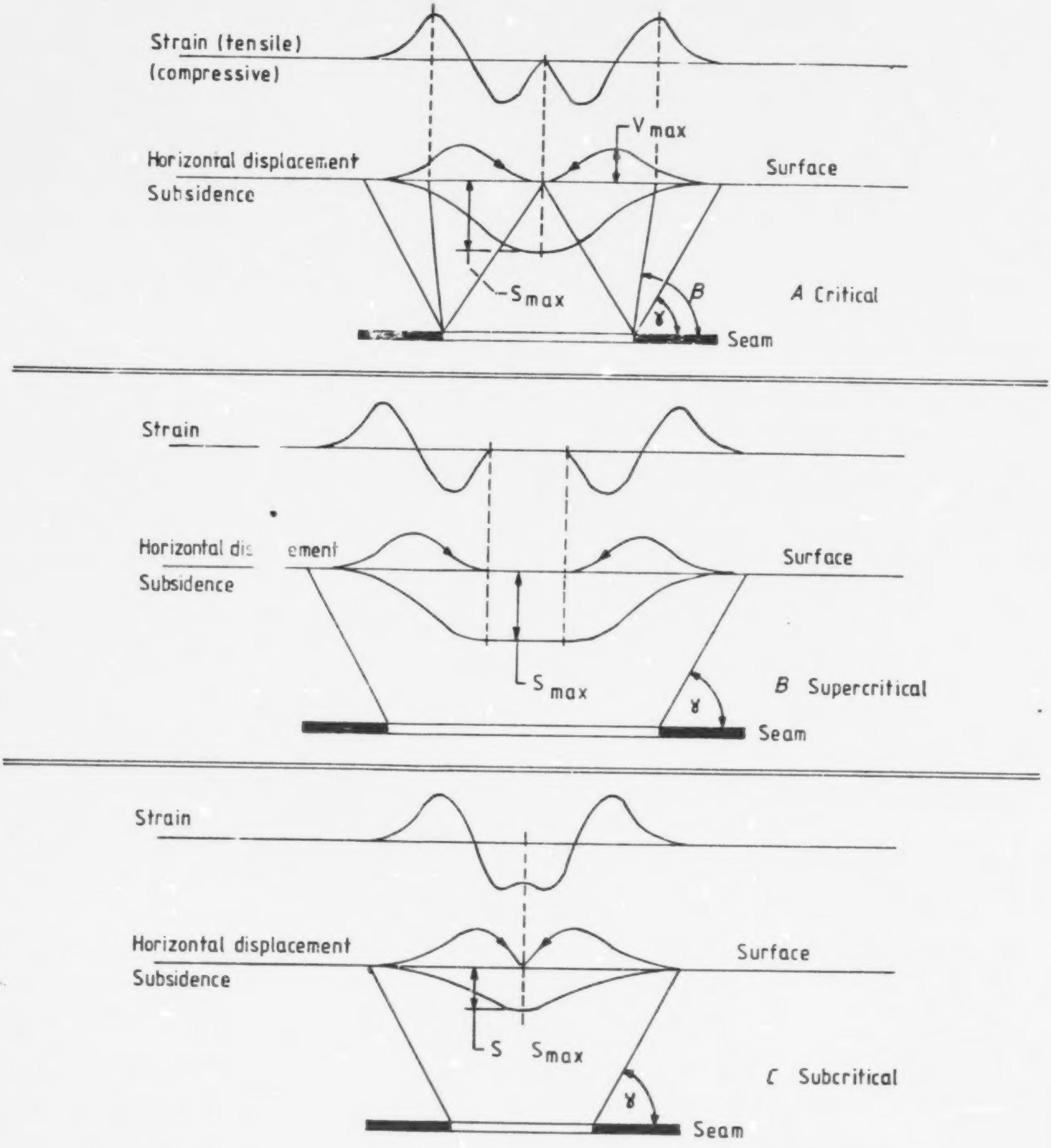
Multi-seam Working

Another characteristic, revealed by analysis of empirical data, is the apparent superimposition of subsidence profiles created by more than one working either in the same seam (Figure 4.5a) or in seams above or below (Figure 4.5b). These show that, in general, as the displacements from one trough are superimposed on those already existing the relative horizontal displacements or strains can be either tensile (positive) or compressive (negative), and these act in an arithmetical manner. For example, an area of residual tension (positive), when influenced by compression (negative) of a similar magnitude from a later working, could be expected to return to its original state.

Empirical research in coalfields throughout the world has shown that whilst the trough shape is similar, the key parameters defining magnitude and extent can vary, eg angle of draw, maximum possible subsidence (as a percentage of extracted height). Thus the importance of direct measurement in defining these movements in each coalfield is evident.

Figure 4.5

CRITICAL SUBSIDENCE
(After United States Bureau of Mines)
(Ref 4.102)


Strain (tensile)
(compressive)
V max
Horizontal displacement
Subsidence
Surface
S max
β
γ
A Critical
Seam
Strain
Horizontal displacement
Subsidence
Surface
S max
γ
B Supercritical
Seam
Strain
Horizontal displacement
Subsidence
Surface
S
S max
γ
C Subcritical
Seam

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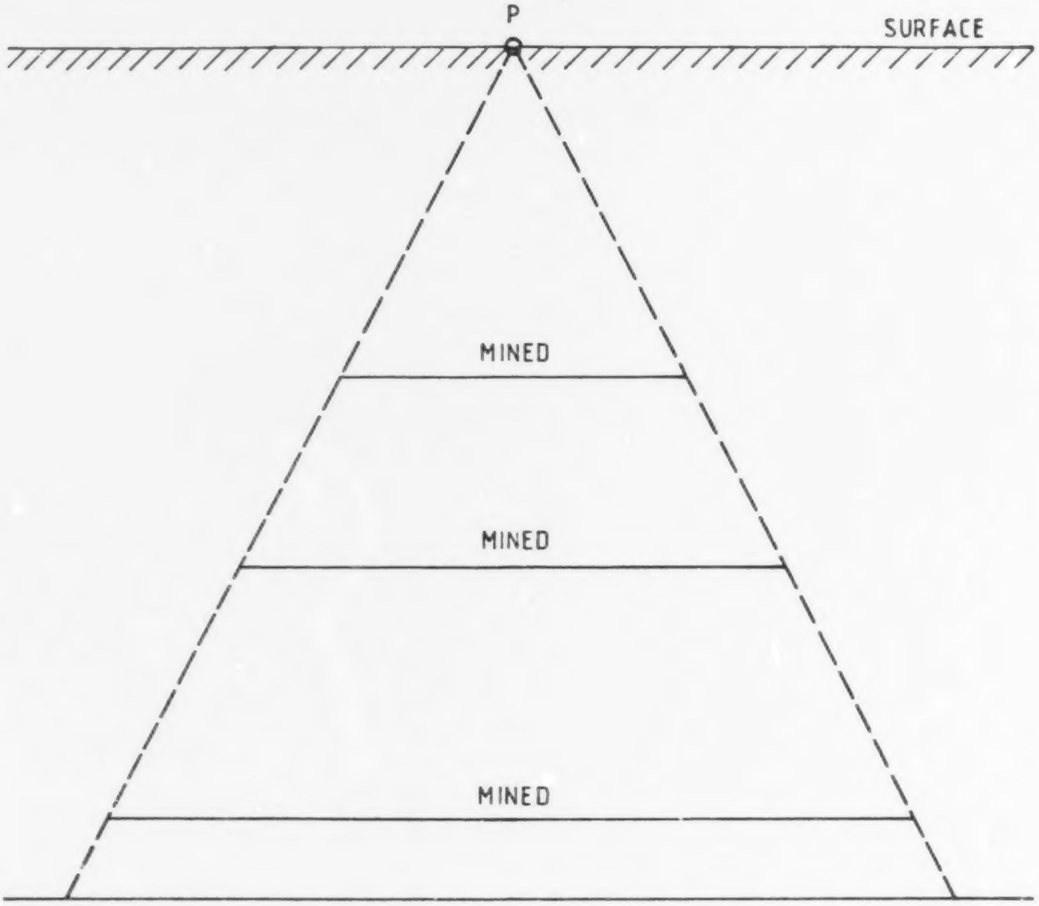
EQUIVALENT SUBCRITICAL AREAS
(after U.S.B.M.)
(Ref 4.102)


P
SURFACE
MINED
MINED
MINED

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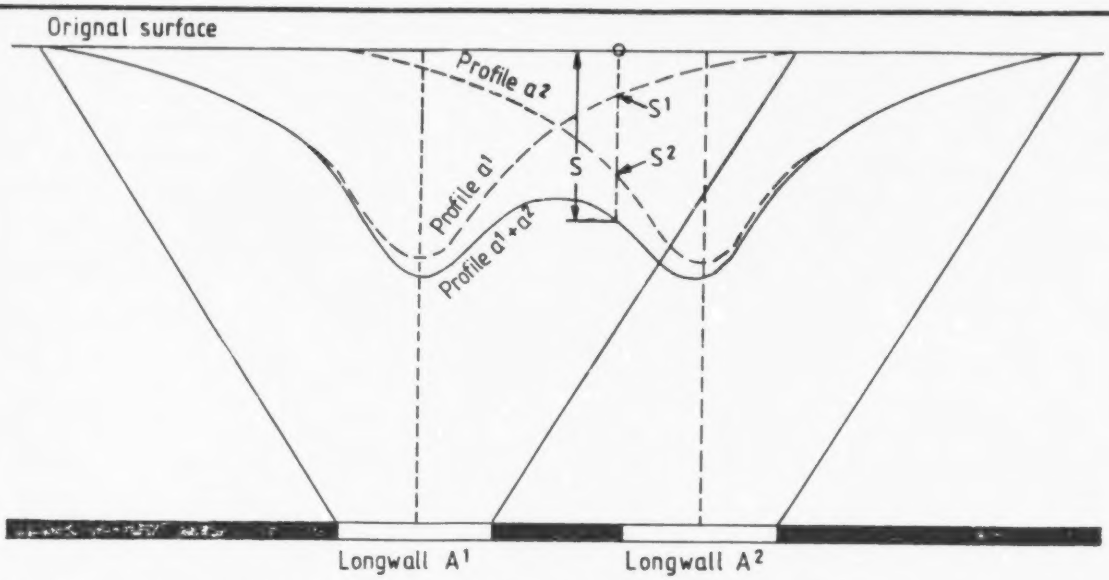
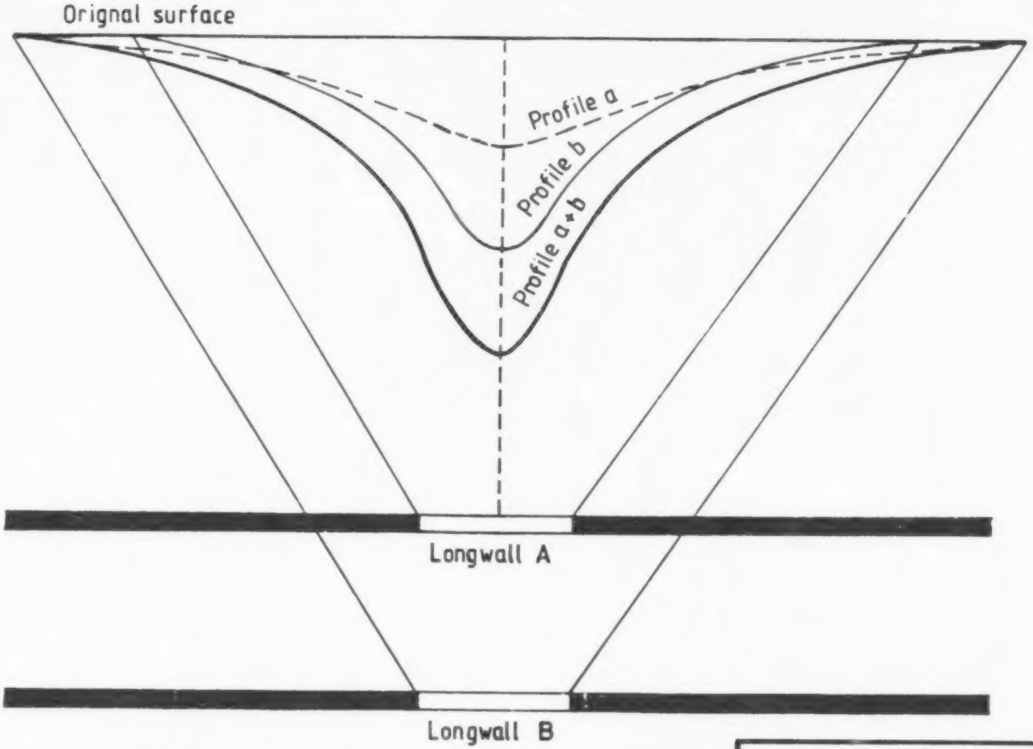
SUPERIMPOSITION OF SUBSIDENCE PROFILES


Orignal surface
Profile a²
Profile a¹
Profile a¹+a²
S
S¹
S²
Longwall A¹
Longwall A²

a) Adjacent longwall panels in the same seam (after USBM Ref 4.102)


Orignal surface
Profile a
Profile b
Profile a+b
Longwall A
Longwall B

b) Panels in different seams

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Influence of Site Conditions and Local Geology

General

The previous outline of a uniform subsidence trough applies to the majority of observations recorded. However, a significant minority display anomalies which on closer study can be related to specific strata or near-surface geological environments.

These anomalies can be associated with:-

- depth
- lithology of interburden strata
- topography
- outcropping strata
- near-surface deposits
- hydrogeology
- strata structural characteristic (eg discontinuities and bed separation)
- natural pre-existing features (eg old landslips)
- man-made surface or underground features (eg old mine workings)
- previous ground deformation from old workings.

Any of these features when disturbed by longwall mining may act to produce ground movements significantly different from the expected movements (sometimes spectacularly so).

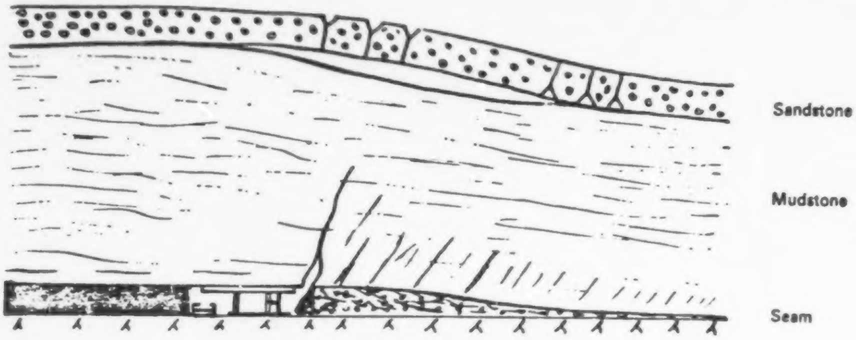
Offshore Coalfields

In an offshore coalfield, such as at Sydney, the paramount consideration must be to keep the sea out of the workings and any mechanism that produces cracking at the surface is of particular relevance. Of the above items, the following merit close investigation (see Figure 4.6):-

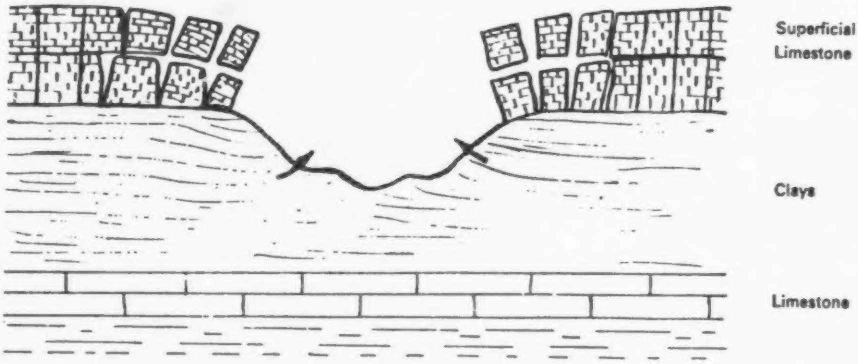
(i) The tendency of massive jointed rocks outcropping as an escarpment to concentrate movement, even producing large cracks at the surface (however, these may be of limited depth).

(ii) The possibility in limestone, with significant ground water flow, of inducing collapse of natural underground caverns.

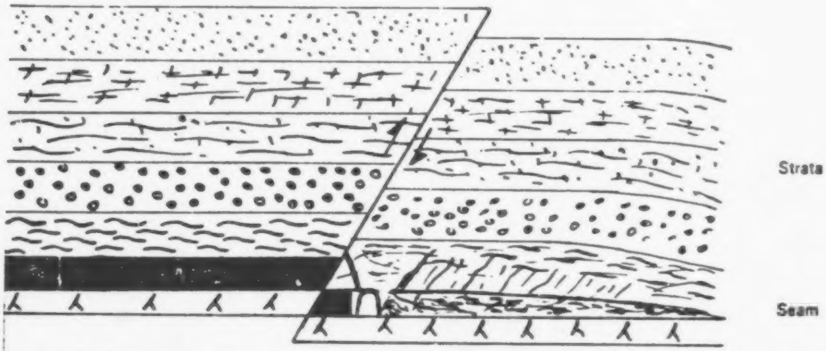
TYPICAL CAUSES OF ABNORMAL SURFACE MOVEMENTS
(After Forrester and Whittaker)
(Ref 4.103)


Sandstone
Mudstone
Seam

(a) Surface fissuring by bed seperation (due to undermining).


Superficial Limestone
Clays
Limestone

(b) Surface fissuring by valley bulging (not due to undermining).


Strata
Seam

(c) Surface step at fault outcrop (due to undermining).

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(iii) Major strata discontinuities, especially fault zones, induce concentration of subsidence movement and sometimes cracking of the surface (eg along deep seated fault planes).

(iv) Large scale movements from mining can directly induce major fracturing of outcropping strata (Figure 4.6).

(v) Ground water regimes are altered by mining subsidence, with possible effects of creating underground reservoirs, increasing erosion of underground channels, etc. Underground collapse may then lead to surface subsidence in excess of extracted height.

(vi) Near surface unconsolidated deposits may settle during mining subsidence such that maximum subsidence exceeds extracted seam height.

Influence of Time

The influence of time on the incidence of ground movement due to mining is an important aspect. The period of ground instability for a given point on the surface, due to undermining, is a function of the extent and depth of the underground workings. Instability occurs during the period that the mineral is being worked within the area of influence of that point. Most movement at the surface usually finishes soon after (within seven days) underground working ceases. A small amount of residual subsidence (5 to 7% of the total) can take place during the month following cessation of underground working. Research in the UK into the post-mining subsidence period has shown that it can extend to 18 months in some cases.

The main causes of subsidence long after mining has ceased include:-

- time dependent behaviour of the rocks surrounding the mining horizon
- gradual closure of zones of incomplete covergence which include bed separation at partings
- changes in support conditions of goaf area. Water often plays a role in post-mining subsidence. For example, in those strata having minerals which react with water to give significant reductions in strength, it may lead to further settlement of relatively shallow goaf regions. Pillared workings which later become inundated can result in the pillars tending to punch into a weakened seatearth thus leading to surface subsidence.

In areas where the interburden strata include a significant proportion of massive beds (eg in parts of the USA), the initial onset, development and residual effects all take longer than in areas where the proportion is low (eg many UK coalfields).

Sydney Coalfield

General

A brief discussion of the geology and character of longwall mining operations within the Sydney Coalfield is presented in Section 2. The stratigraphic section of the coalfield is repeated as Figure 4.7 and the key longwall operating parameters are restated for the convenience of the reader.

Longwall Mining Operations

The year 1984 opened with three mines working longwalls at depth under the ocean, each in a single seam:-

- No 26 Mine extracting 2 m at 700 m below seabed, 7 km offshore
- Lingan Mine extracting 2 m at 500 m below seabed, 4 km offshore
- Prince Mine extracting 2 m at 200 m below seabed, 2 km offshore

In addition the operator, CBDC, has proposals under consideration for new mine developments, all involving offshore/submarine mechanised longwall workings (see Figure 4.8).

CBDC has adopted codes of practice, in addition to the prevailing statutory requirements, which require precalculation of estimated seabed subsidence. A design for any longwall is only accepted if it fulfills these requirements. The maximum total predicted seabed strain should not exceed 8.5 mm/m tensile strain to avoid excessive cracking of the interburden rocks. This is based mainly on past experience within the coalfield, together with experience and practice in offshore coalfields of similar geological conditions. In certain circumstances the amount of coal extracted can be restricted due to subsidence considerations alone, for example: where other seams contain old workings; where more than one seam is to be worked; or where the seam is relatively shallow and thick. Recent research has indicated potential for increasing this limit. (Ref 4.C, Aston and Whittaker 1982).

It has been shown that the magnitude of surface movements depends principally upon the depth, dimensions of extraction and prevailing ground conditions. Any subsidence measurement system for the Sydney Coalfield must therefore be suitable for monitoring movements in a range defined by the proposed future workings.

At existing mines, over the next five years, single seam longwall workings will extract heights of between 1.5 and 2.5 m at depths of 200 to 900 m below the seafloor/rockbed at face lengths of 100 to 200 m.

New mine proposals involve longwalls at depths of up to 1200 m, with extracted heights of up to 3.5 m and with face lengths up to 250 m. Ultimately it is hoped to work second and third seams.

Using existing prediction procedures, a single panel would be unlikely to exceed the maximum tensile strain limit. However, the presence of old

SYDNEY COALFIELD — SEQUENCE OF SEAMS

(Cape Breton Development Corporation)

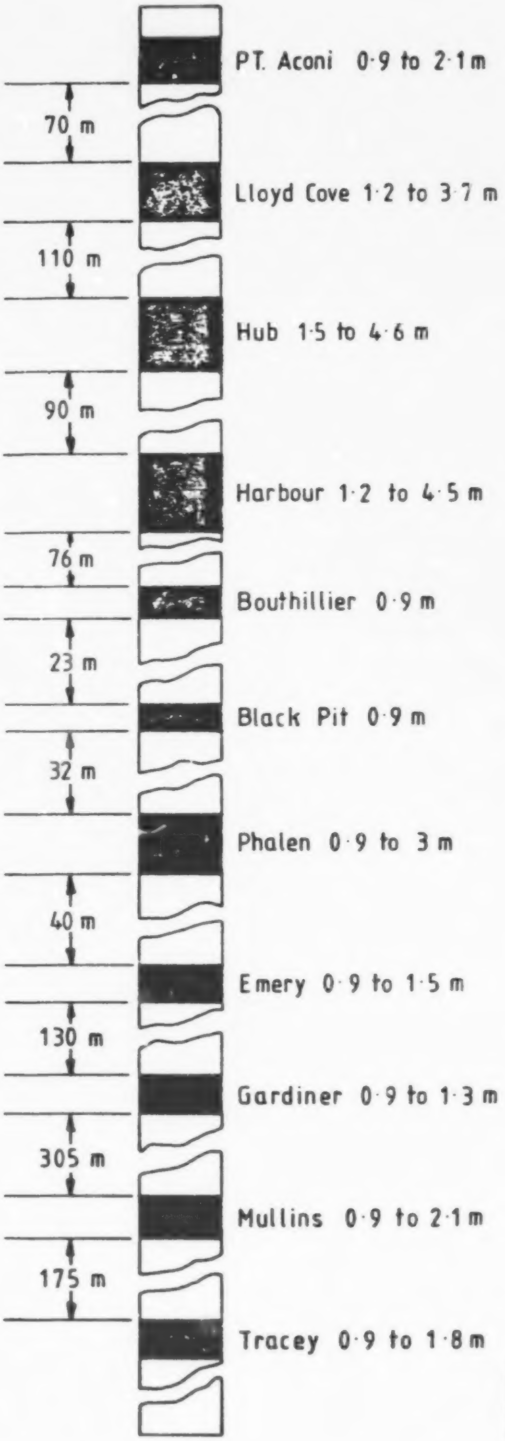
PT. Aconi 0·9 to 2·1 m
70 m
Lloyd Cove 1·2 to 3·7 m
110 m
Hub 1·5 to 4·6 m
90 m
Harbour 1·2 to 4·5 m
76 m
Bouthillier 0·9 m
23 m
Black Pit 0·9 m
32 m
Phalen 0·9 to 3 m
40 m
Emery 0·9 to 1·5 m
130 m
Gardiner 0·9 to 1·3 m
305 m
Mullins 0·9 to 2·1 m
175 m
Tracey 0·9 to 1·8 m

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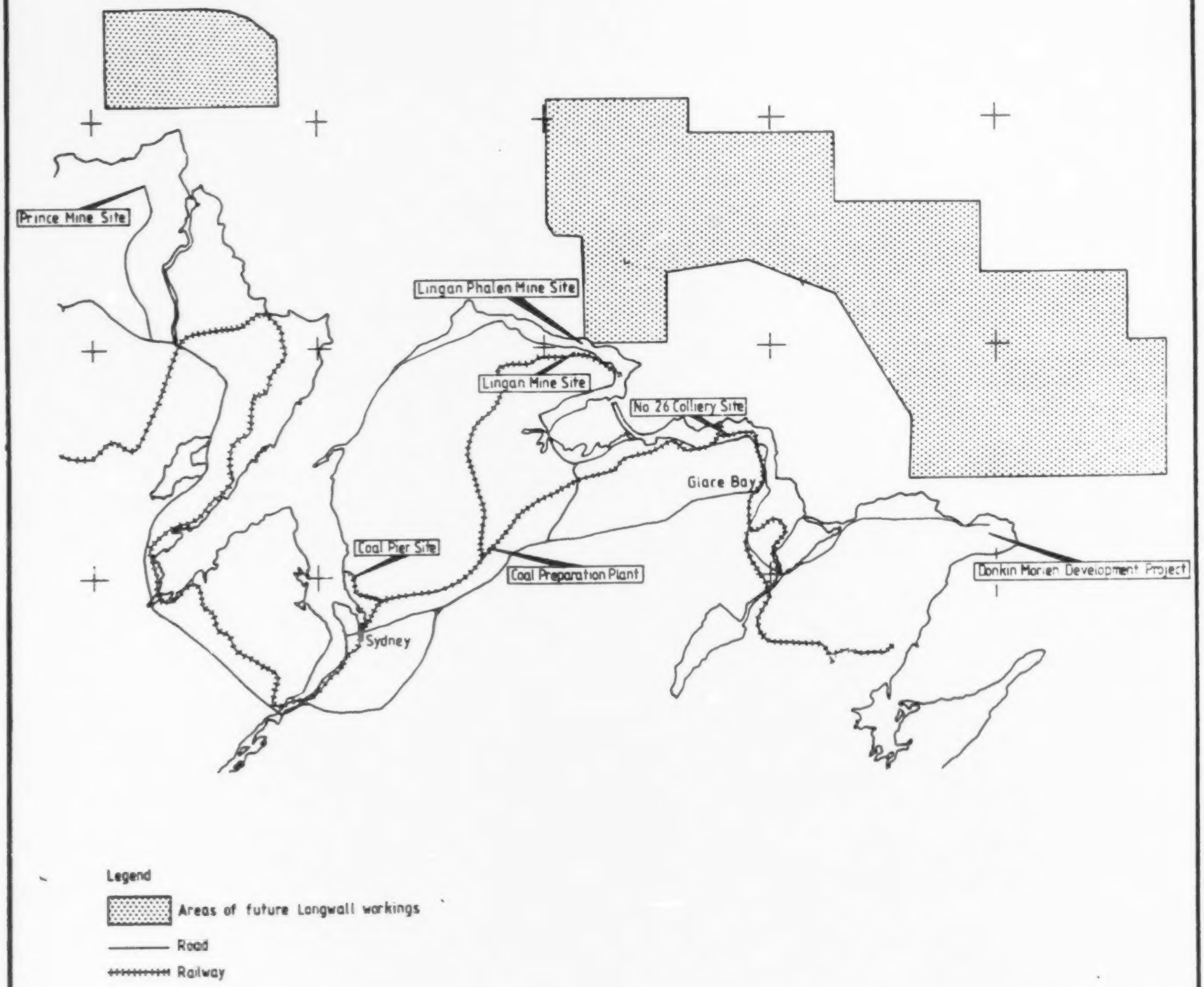
Figure 4.8

SYDNEY COALFIELD

LOCATION OF FUTURE LONGWALL WORKINGS


Prince Mine Site
Lingan Phalen Mine Site
Lingan Mine Site
No 26 Colliery Site
Glace Bay
Coal Pier Site
Coal Preparation Plant
Sydney
Donkin Morien Development Project
Legend
Areas of future Longwall workings
Road
Railway

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workings, of pillars between adjacent longwall workings and the intention to work additional seams later, mean that often the maximum strain requirement will restrict the dimensions of mine workings and hence extraction of coal.

Future movements induced on the seabed will range from subsidence of approximately 0.3 m to 3.0 m and strains from 0 mm/m to at least 8.5 mm/m tension (15 mm/m compressive). These are tabulated in Table 4.1 for both single seam and combined subsidence for projected longwall mining conditions.

The duration of measurements under such circumstances is illustrated for a longwall advance/retreat rate of 28 m/week in Table 4.2. The most suitable sites for future subsidence research may prove to be Prince Mine for single seam study and the new Lingan Phalen Mine where the first longwall panels may be operating in two years time, within 1 km of the shore. At both sites sea water depths are relatively shallow and "hardwire" links from seabed instruments to shore could be considered. In addition, subsidence strains will be of significant magnitude for early development of seabed measurement techniques. Also at Lingan the Upper Harbour seam has already been worked in this area and access for in-mine monitoring of subsidence may be possible.

Summary

It has been shown that the magnitude of surface movements depends principally upon the depth, dimensions of extraction and prevailing ground conditions. Any subsidence measurement system for the Sydney Coalfield must be able to monitor movements in a range defined by the proposed future workings.

Movements to be induced on the seabed in future range from maximum subsidence of approximately 0.3 m to 3.0 m and strains from 0 mm/m to at least 8.5 mm/m tension (15 mm/m compressive).

The principal benefits of any submarine subsidence data collection can be summarised as increasing the understanding of strata deformation, such that in future more coal can be extracted from a given area, with the same, or a higher, degree of confidence than before.

Particular importance must be placed on the need for a monitoring scheme to incorporate:-

(i) Base reference monuments in stable ground, away from the influence of mining.

(ii) Measurements to cover the magnitude and full extent of permanent surface deformation, preferably from at least two adjacent longwall panels.

(iii) Measurements to cover the full extent of the development of transient surface movements.

TABLE 4.1

POSSIBLE RANGE OF MAX SEABED MOVEMENT FROM LONGWALL MINING SYDNEY COALFIELD

(using NCB Subsidence Engineers Handbook)

Case	Extracted Height, M (m)	Depth of Seam, h (m)	Width/Depth Ratio, w/h Approx	Predicted Max Subsid (m)	Predicted Max Tensile Strain (mm/m)
Single Seam Subsidence					
Prince Mine	2.0	200	0.50	0.9	+3.7
Lingan Harbour Mine	2.0	500	0.40	0.7	+1.2
Lingan Phalen Mine	2.0	200	0.50	0.9	+3.7
No 26 Mine	2.0	700	0.29	0.4	+0.4
Donkin Mine - av ht for 1 longwall	2.0	190	0.63	1.2	+4.6
- max ht for 1 longwall	3.5	400	0.50	1.7	+3.5
- max ht for 7 longwalls	3.5	600	1.40	3.1	+3.5
Combined Subsidence					
@ Lingan (theoretical max)	-	-	-	1.6	+4.9
@ Donkin (theoretical max)	-	-	-	2.9	+8.1

TABLE 4.2

ILLUSTRATION OF TIME PERIOD FOR MEASUREMENT

(for a single longwall affecting one fixed surface point and representative conditions)

Seam Depth	200 m (min)	700 m	1200 m (max)
Range of Influence (1.4 x depth)	280 m	980 m	1680 m
Duration Point is Moving (If longwall moves at 28 m/week)	10 weeks	35 weeks	60 weeks
Duration for Measurements (inc 4 weeks before and 25 weeks after)	39 weeks (¾ year)	64 weeks (1¼ years)	89 weeks (1¾ years)

(iv) Measurements to be taken at sufficiently regular time intervals before, during and after mining to determine time-related factors.

(v) Detection and measurement of concentration of movement (eg cracking).

Subsequent data analysis and presentation must include derivatives of displacement measurements. These in turn will influence the design of the monitoring scheme, layout of monuments, etc.

The performance of any instrumentation scheme to obtain these measurements is controlled by their resolution, reliability and robustness. In the Sydney Coalfield where the onset and extent of ground movement must be detected, a high accuracy of measurement is required. For example, measurement of displacement to within 10 mm should be sought.

A suitable site for instrumentation development may prove to be the new Lingan Phalen Mine planned to commence production in the next year or so. This site is relatively close to shore and has potential for in-mine monitoring to supplement any seabed monitoring.

4.3 - CURRENT LANDBASED SUBSIDENCE INSTRUMENTATION SYSTEMS

Preamble

In the past surface subsidence was measured by conventional survey techniques and instrumentation. A review of practice in the UK, USA and elsewhere, is given below. As research programs were formulated to investigate specific aspects in more detail, more precise geodetic survey instruments were used. Experience led to areas where improvements could be made and new techniques were developed. As new survey instruments became available, these too were adopted by subsidence researchers (eg electromagnetic distance measuring (EDM), automatic data capture, "total stations" and theodolites). In recent years the need to gain subsidence data in remote locations and in severe environments (eg Rocky Mountains) led to the adaptation of such techniques for remote data collection. This subsea project can be considered as the latest step in that progression.

However, mining subsidence is just a special type of ground movement and much research has been done in the related field of geotechnical instrumentation. The study of foundations and earth/rock structures often requires detailed investigation not only of the engineering properties of the ground but also of deformation on the surface or at depth. Certain of the instruments developed have been adapted for subsidence measurements. In addition, some instruments and techniques measure the same type and magnitude of ground movement as those induced by mining, so could be considered for subsea use.

Ground movements are measured by various optical surveying techniques and/or by a wide variety of fluid, rod, wire, pendula and level actuated devices, inclinometers and extensometers, all of varying accuracy and degrees of refinement. These are reviewed below. Further, direct measurement of a derivative of subsidence, namely tilt, is covered under the heading "Derivative Measurements". Finally, possible future developments, particularly in use of geophysical techniques are discussed.

Review of Subsidence Measurement Practice

United Kingdom

Mining subsidence has been observed in the UK for many years; the NCB's prediction models have been derived empirically from the data obtained by the observation and analysis of several hundred field cases. It should be noted, however, that the bulk of this work was completed some years ago. The relatively small number of observations presently being undertaken are for acquisition of local data, (as distinct from UK average values), and a few other refinements. Most of these later observation programs were initiated before the more advanced electronic surveying equipment came into common use. They relied instead on conventional surveying techniques with precise levelling by geodetic level and invar staves.

The more basic type of surveying equipment available also tended to preclude the measurement of the absolute movement of surface points. Relative movement, enabling the calculation of strain values, but not of lateral movement, was more generally observed. The relative movement was measured either by direct taping, with corrections for temperature and tension, or by extensometer. Earlier cases where absolute movement had been observed were measured using first order traversing or triangulation techniques.

More recently, observations have been taken using the most up to date EDM equipment in conjunction with conventional methods. Other useful data have been accumulated by the use of strain gauges and by electrolevel, which are especially useful in determining the onset of subsidence. All the aforementioned surveys were undertaken using a variety of stations and techniques, depending upon the type and accuracy of data required.

Observations planned for the future in the UK will continue to use increasingly accurate EDM equipment and include use of the total station concept. This comprises: electronic theodolite, electro-optical distance meter, microprocessor and data collector used together with a microcomputer printer, plotter and digitiser.

It should be noted however, that accurate as the latest EDM equipment and the total station are for determining the absolute position of a point, for the measurement of the relativity between stations, conventional taping methods remain more accurate. Vertical movement continues to be observed by the accepted and most accurate method of precise levelling.

Various layouts adopted with monitoring programs for measurement of subsidence in the UK are discussed in Section 4.5.

North America

In 1978 the US Bureau of Mines initiated a long term mining subsidence research program. The immediate aims were to determine practical methods and equipment for the field measurement of subsidence. These would generate data which would be supplied to co-operating mining companies and used by the USBM to achieve the longer term objectives of developing and validating prediction techniques applicable to mines in the west, mid-west and east of the USA.

In a paper in December 1981, F K Allgaier (Ref 4.29) reviews progress in the west. A similar layout of stations or monuments has been adopted throughout to measure as many movement parameters as possible. Emphasis is place on tested, proven, practical and user-oriented aspects of instrumentation. The basic layout adopted is that of single lines of stations orientated both longitudinally and transversely over the panels and also supplemented by 45° lines over the corners at the start/stop positions.

Again conventional survey techniques have been adopted, supplemented by electronic theodolites, as these were developed. Measurements include traverses to obtain x, y, z co-ordinates, geodetic measurement of angles and distances; direct levelling and chaining (using a steel band/tape). The approach is similar to that adopted in the UK.

It is clear that US experience has endorsed that gained in the UK concluding that any subsidence monitoring scheme is a compromise between extent/accuracy of measurements and the effort/cost required to obtain the measurements. In addition, rugged terrain and severe climate further complicate the choice of optimum system. Great benefits and improved cost effectiveness have been gained by adoption of electronic theodolites and computer processing of data.

In addition to routine observation programs being operator orientated, the US Bureau of Mines' subsidence research program is directed towards the aims of developing prediction procedures from a firm data base. One of the instrumentation schemes arising from the research is the automatic data acquisition system (ADAS), described below. Mention is also made in the literature on aerial photographic surveys, Ref 4.27/8, although their use seems to be more for overall survey control than measurement of displacements.

The use of aerial photogrammetry has also been adopted in subsidence research in Canada. CANMET's program with BC Coal for subsidence measurement in the Rocky Mountains in British Columbia Ref 4.27 used aerial photography for overall and periodic survey control with intervals of approximately one year. This program also used a laser tacheometer (AGA 700) for conventional geodetic survey work and developed a computerised telemetry system for the continuous monitoring of ground tilt.

Elsewhere

Current practice in 10 additional countries is mentioned in the various references discussed in 4.6 below and listed in Appendix 4.2. These cover western and eastern Europe, Asia and Australia. There are two common features:-

(i) the predominant use of conventional surveying instrumentation;

(ii) the widespread integration of both surface and rock mass deformation monitoring to provide a more comprehensive picture of the overall ground behaviour.

In addition some interesting developments in instrumentation are noted. These include: the use of electrical resistivity for examining behaviour of near surface rocks in Poland; use of a "string" method for continuously measuring pipeline deformation in Czechoslovakia; use of photogrammetry for surface observations in Germany, Russia and Poland as well as in Canada; the use of three geophysical techniques for detecting cavities in underground gasification of coal, namely:-

(i) high frequency electromagnetic (HFEM) scans between pairs of boreholes;

(ii) magneto telluric surface geophysical technique;

(iii) the use of potentiometric transmitters for continuous detection of relative displacement between fixed flexible connectors between observation points.

Optical Survey Systems

Geodetic Systems

The remote and/or systematic monitoring of spatial deformation of the ground by geodetic methods involves the measurement of horizontal and vertical angles and of distances to a series of ordinary and light reflecting targets, mounted on fixed reference monuments or stations. The measurements taken are computed to give the three dimensional (3-D) or x, y, z co-ordinates of points in the deforming ground. When measured at intervals through time, the displacements in 3-D can be calculated. Three principal methods can be used:-

(i) 3-D triangulations, ie measurement of all horizontal and vertical angles between the monuments.

(ii) 2-D trilateration plus levelling, ie measurement of slope distances plus levelling to give reduced plan distances of each side of a series of triangles.

(iii) 3-D trilateration, ie measurement of distances in relation to fixed reference points in stable ground. In addition various combinations of the above, ie of angle, distance and level measuring (as necessitated by site conditions) can be used.

All of these systems are designed to detect the onset of ground deformation and very high instrument accuracies are required, in the order of mm. A good discussion of accuracies is given by both Penman and Ashkenazi (Ref 4.103).

These systems use the following instruments:-

- Geodetic "one second" theodolites
- Precise levels
- Lightwave distance measures (for greater distances)
- Tapes or tape extensometers (for smaller distances eg 10 m).

There is a wealth of technical literature available on the first three especially from manufacturers such as Kern, Wild, Aga, etc. Their application is conventional and assured to be widely understood by the reader. The extensometer is simply a more precise way of measuring distances with a steel tape and is discussed later.

Recent Developments

Recent developments in technology, especially sophisticated electronics, have produced efficient survey systems at a reasonable cost. These are based around rapid measurements with automatic data collection, storage and transfer to computer for processing to the final drawings.

For example, in field measuring equipment, the infra-red EDM instruments have improved in range to achieve measurements of up to 2.5 km with only one reflector. Accuracy of ± 5 mm plus 5 parts per million is now common. The flexibility of these instruments is improving as means of transferring data or sound along the infra-red beam are developed. Perhaps the greatest progress in obtaining measuring efficiency has come with the integration of the EDM with an electronic theodolite - the total station. These are now discussed.

The Total Station is an electronic theodolite integrated with an EDM, (see Figure 4.9, Ref 4.126). This instrument allows the measurement of horizontal and vertical angles together with the slope distance. Angular accuracies of one second of arc plus a linear accuracy of ± 3mm plus 5 parts per million can be achieved.

These theodolites can incorporate a novel levelling system with which the tilting axis height is held constant. An electronic system automatically reads and displays the angular values. The EDM measures the phase difference between the transmitted and reflected measuring signal from which the slope distance is calculated and displayed digitally. Furthermore, the use of an in-built computer can enable the instrument to be calibrated in order to remove any remaining effects of optical or mechanical misadjustments.

These instruments can also incorporate automatic data capture. That is, the data are automatically transmitted to a recording instrument for storage. This can then be fed into a computer which accepts the data for further processing, eg to carry out the various survey calculations, re-sections, co-ordinates, etc. Figure 4.10 illustrates the overall arrangement.

Figure 4.9

THE KERN TOTAL STATION
(after Hodges et al)
(Ref 4.126)

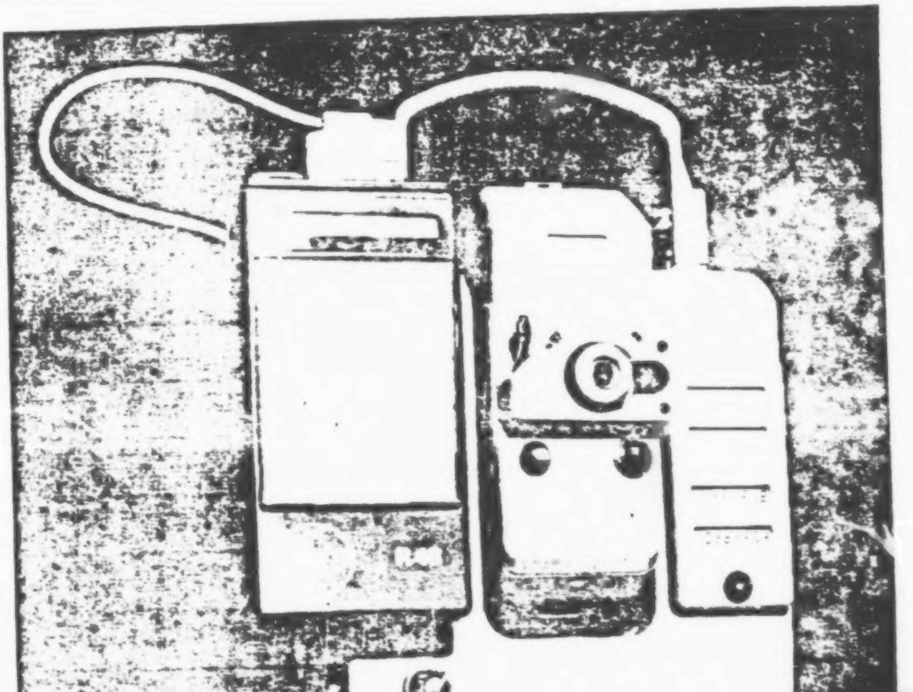

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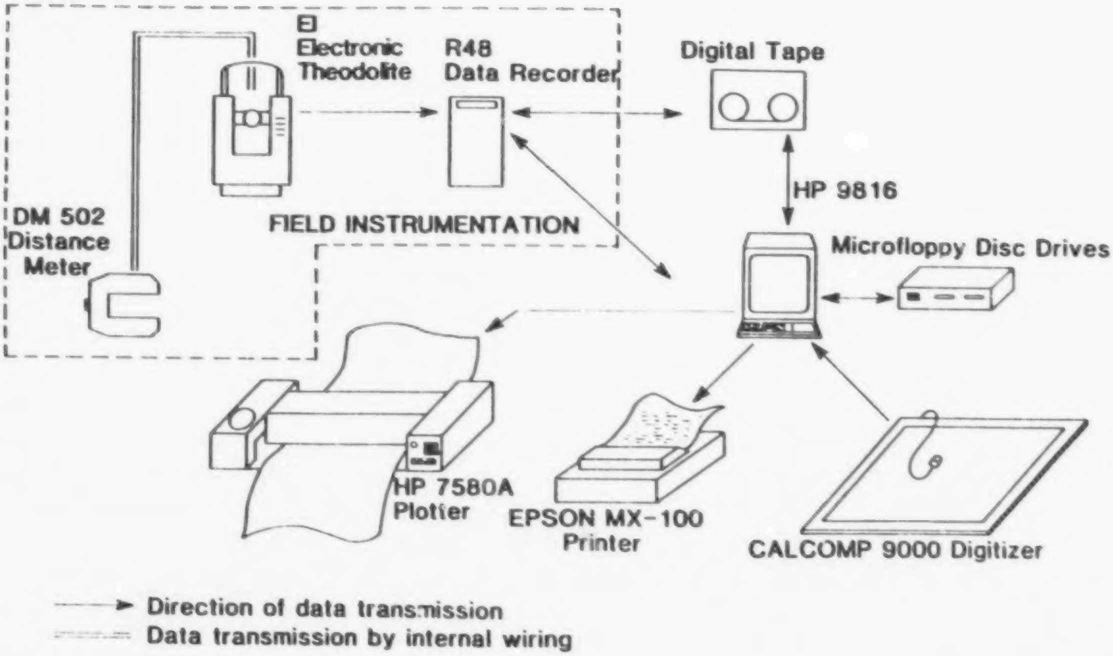
Figure 4.10

ARRANGEMENT OF TOTAL STATION DATA AQUISITION & PROCESSING
(after Hodges et al)
(Ref 4.126)


Electronic Theodolite
R48 Data Recorder
Digital Tape
HP 9816
DM 502 Distance Meter
FIELD INSTRUMENTATION
Microfloppy Disc Drives
HP 7580A Plotter
EPSON MX-100 Printer
CALCOMP 9000 Digitizer
Direction of data transmission
Data transmission by internal wiring

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These instruments not only provide accurate and rapid measurements of observation points but are equally suited to setting-out and controlling survey tasks (ie they are multi-purpose instruments). Their use in land-based subsidence monitoring has improved quality and speed and reduced the effort involved in obtaining comprehensive data in a relatively short time.

Tape Extensometer

Surface Applications

The traditional method of measuring the distance between subsidence observation stations is that of taping. A calibrated stainless steel tape, graduated at each end, is held and tensioned between the two points and both graduations read. A temperature correction is made. Although accurate when strictly applied, this method is time consuming and uses a five man team.

The tape extensometer system was developed by adapting borehole extensometer systems to the traditional tape, to enable the tape to be tensioned and read quickly and precisely. The calibrated stainless steel tape has an anchor unit at one end and a measuring unit at the other, which combines tensioner and graduated/micrometer scale. Both units fit onto registers in the observation stations, see Figure 4.11, Ref 4.107. Again a temperature correction is made but the system can be operated by a single person. An accuracy of ± 0.1 mm in 9 m is achieved. The system could be adapted to remote operation and automatic data capture.

Other Deformation Measurement Systems

Lasers

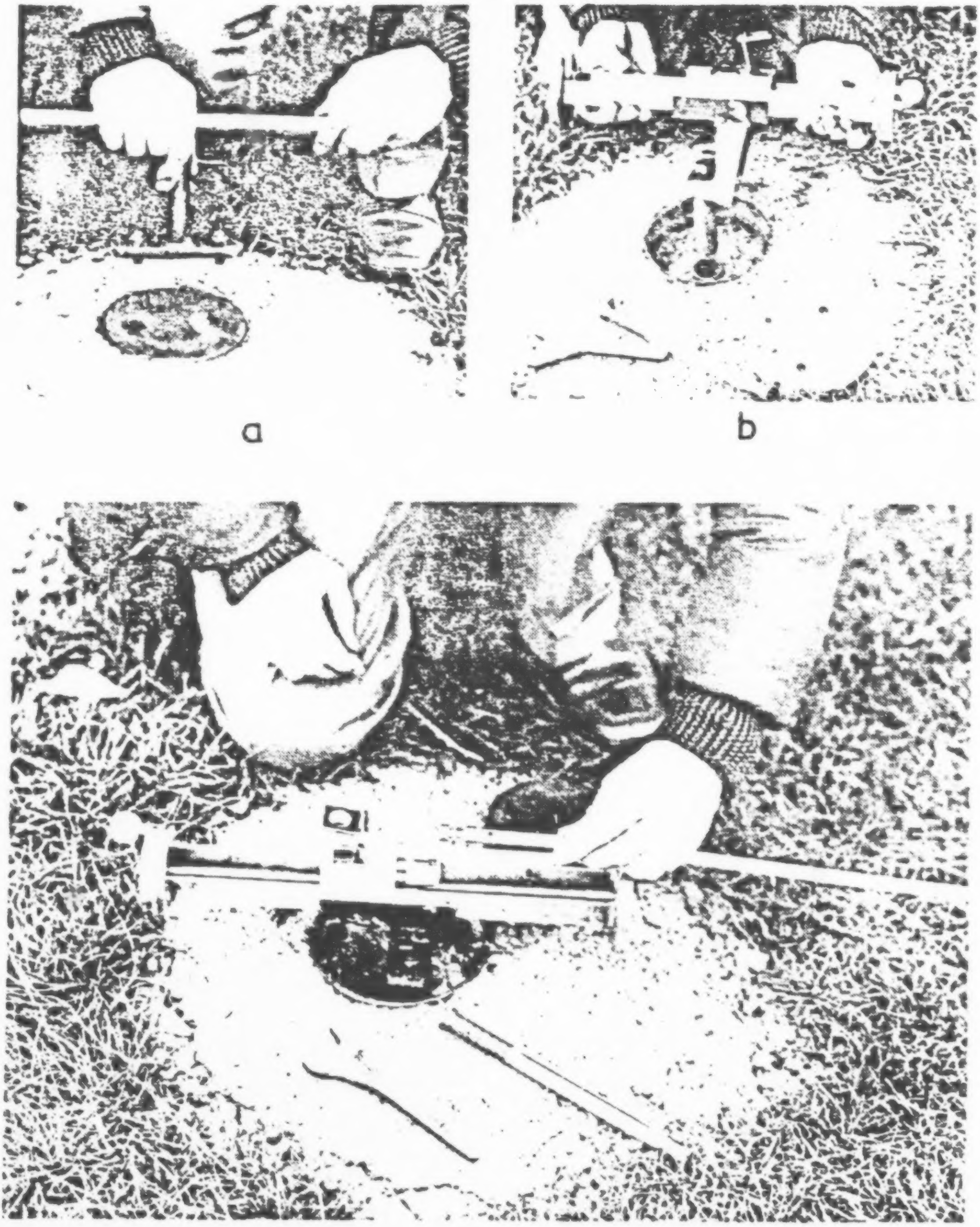
Ground deformations can be measured, using laser light beams, by at least two methods, the first involves measurement of settlement of a point approximately 9 m from the stable reference. The light beam is focussed by a lens placed at the subsiding point onto a photo-electric detector 9 m away. As the lens moves, the spot on the detector moves, data processing displays movement on a chart recorder (see Figure 4.12, Ref 4.103).

The second is used to provide accurate measurements of the deformation of the crest of a dam. Basically a laser light source is fixed on a monument in the stable ground and directed along the dam crest, 0.3 m above ground level. The beam is focussed onto a graduated screen at each observation point in turn. Vertical and horizontal measurements are taken in mm of the position of the beam, at regular time periods. The deformation at each point is then determined.

Fluid Settlement Gauges

An air, water or mercury column is used to transmit a pressure over a distance. Difficulties occur if the difference in level between the measuring tip and the recorder is large, particularly if suctions are involved. A permanent gauge house can incorporate elaborate circulation and de-

TAPE EXTENSOMETER FOR SURFACE STRAIN MEASUREMENT
(After Forrester and Whittaker)
(Ref 4.107)



a b

c

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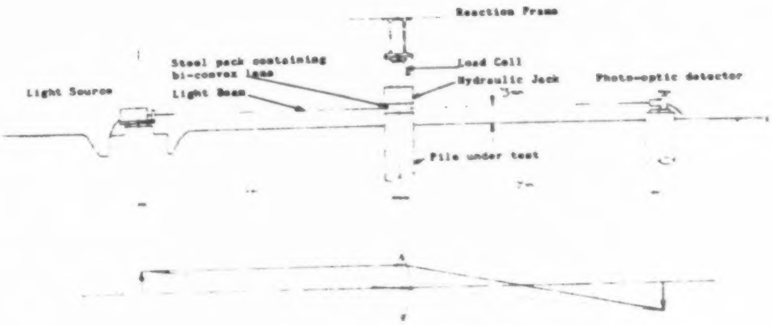
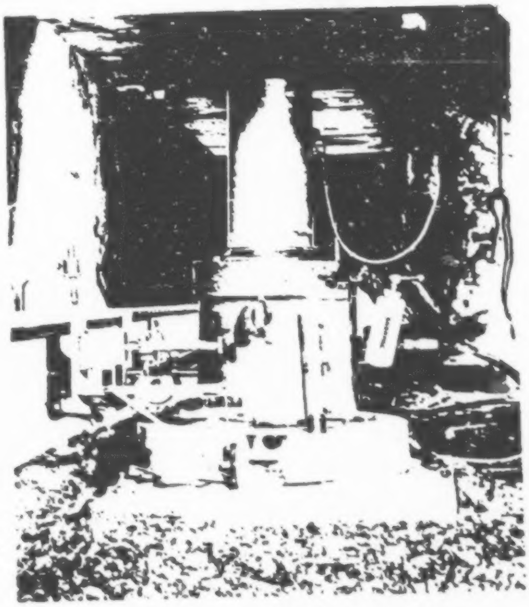
Figure 4.12

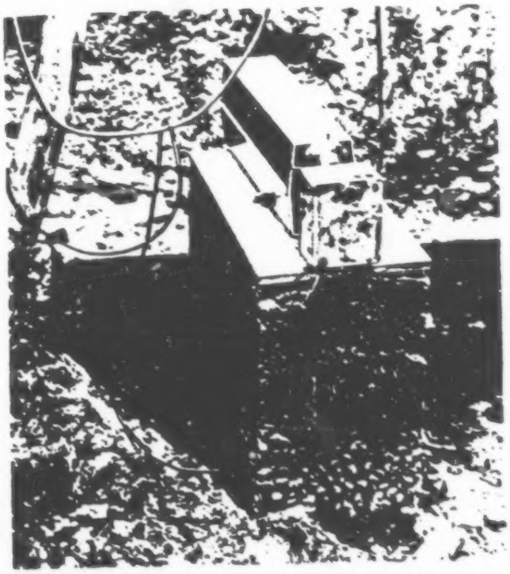
USE OF LASER BEAM TO MEASURE SURFACE DEFORMATION
(After Weeks et al)
(Ref 4.103)


Reaction Frame
Steel pack containing bi-convex lens
Load Cell
Hydraulic Jack
Photo-optic detector
Light Source
Light Beam
3m
Pile under test
7m

Arrangement and principle of Optical Settlement Measurement



Assembly at test pile head showing lens mount



Laser on base

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airing equipment, but a simple portable unit is also needed which requires little de-airing. Difficulties arise in practice in de-airing, such as temperature variations, flow rate effects, mercury column breakdown, electrical pressure transducer vulnerability.

The water overflow gauge is apparently well developed (see Figure 4.13, Ref 4.103). However, difficulties occur when the gauge is below the gauge house and suction is involved, a positive gas back pressure would be better.

The mercury settlement gauge, single or multiple point, has an accuracy of ± 2 mm and operates with up to ± 3 mm difference in elevation between recorder and cell (see Figure 4.14, Ref 4.103). Gauges of this type are being used over very long distances at Tarbela Dam, Pakistan. More recently a constant volume system water gauge has been designed to operate over greater head difference with similar accuracy.

Inclinometers

A "mole" which can be drawn or pushed along a flexible horizontal tube has been used (see Figure 4.15). Further, a water overflow gauge drawn by an air-operated duct, motor-operated from a substantial gauge house, obtained accuracies of ± 2 mm. A simple probe relying on the cable stiffness to "rod" it along the buried tube has also been used.

The principle of measuring horizontal ground movement with an inclinometer is illustrated with a photograph of the instrument in Figure 4.16 (Ref 4.125, Hudson et al 1978).

These instruments are used in vertical boreholes which are lined with aluminium or plastic casing provided with keyways for guide wheels of the inclinometer torpedo. On one side of the torpedo the wheels are fixed and on the other side the wheels have a spring mounting to ensure that one side of the torpedo is running firmly against the keyway. The inclinometer is lowered down the borehole by a cable containing the transducer wires and the measurements of the slope of the instrument are taken at regular increments equal to the distance between the guide wheels.

The horizontal distance between the upper and lower wheels of the torpedo is determined by multiplying the sine of the angle from the vertical by the length between the wheels. By adding these displacements algebraically the horizontal position at any point can be established.

The transducers within the inclinometer torpedo are of two main types:-

(i) strain-gauged cantilever;

(ii) servo-accelerometer.

The servo-accelerometer type is generally more accurate but more expensive. Inclinometers incorporating a pendulum contacting a precision-wound coil have also been used for many years and the technique of a camera photographing a pendulum above a compass face is also used in borehole surveying.

Figure 4.13

WATER OVERFLOW SETTLEMENT GAUGE
(after Penman & Charles)
(Ref 4.103)

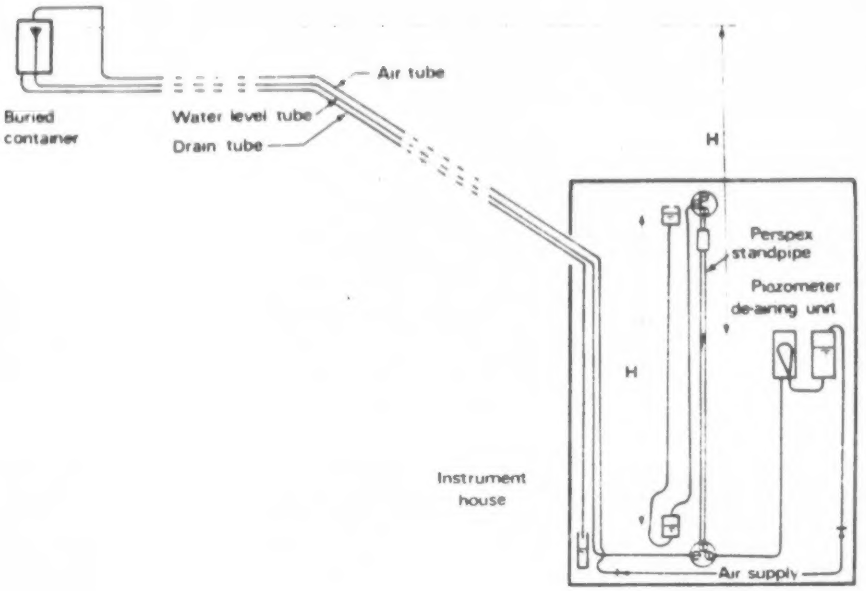
Air tube
Buried container
Water level tube
Drain tube
H
Perspex standpipe
Piezometer de-airing unit
H
Instrument house
Air supply

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Figure 4.14

MEASURING SETTLEMENT GAUGE
(after Irwin)
(Ref 4.103)

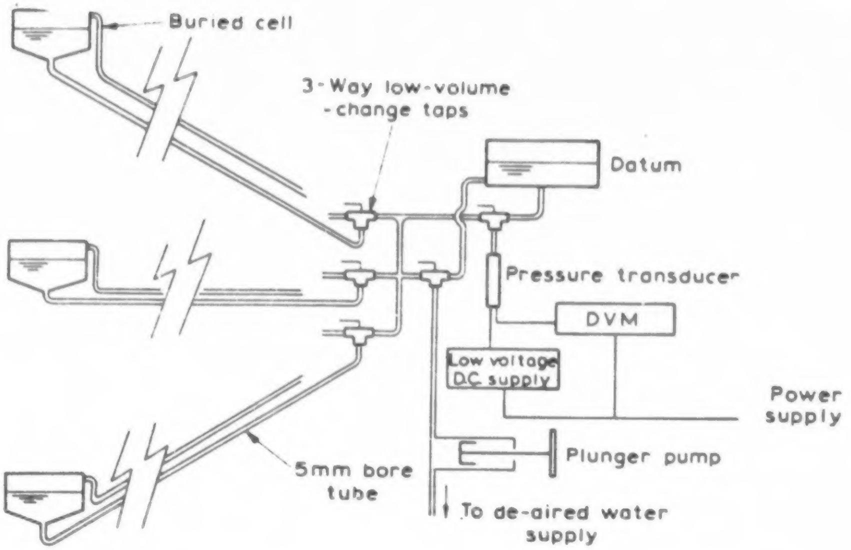
Buried cell
3-Way low-volume -change taps
Datum
Pressure transducer
DVM
Low voltage D.C supply
Power supply
Plunger pump
5mm bore tube
To de-aired water supply

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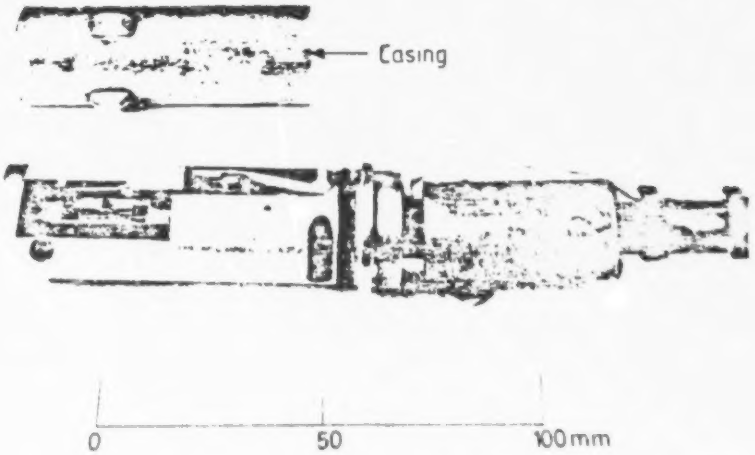
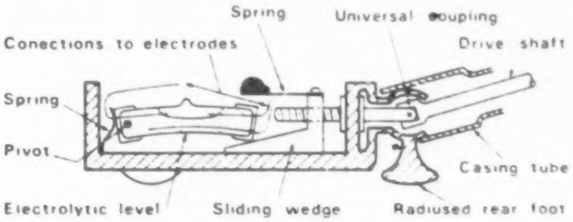
Figure 4.15

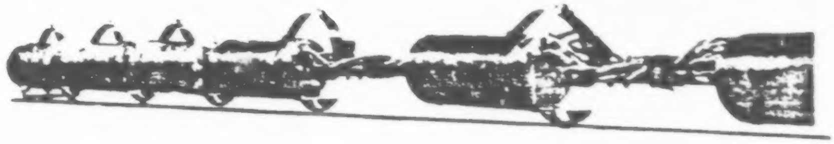
HORIZONTAL INCLINOMETER
(after Cooke & Price)
(Ref 4.103)


Casing
0
50
100mm

Inclinometer with the casing removed.


Spring
Universal coupling
Conections to electrodes
Drive shaft
Spring
Pivot
Casing tube
Electrolytic level
Sliding wedge
Radiused rear foot

Longitudinal section through inclinometer
showing the main components



Part of a train of inclinometers at
close and double spacing

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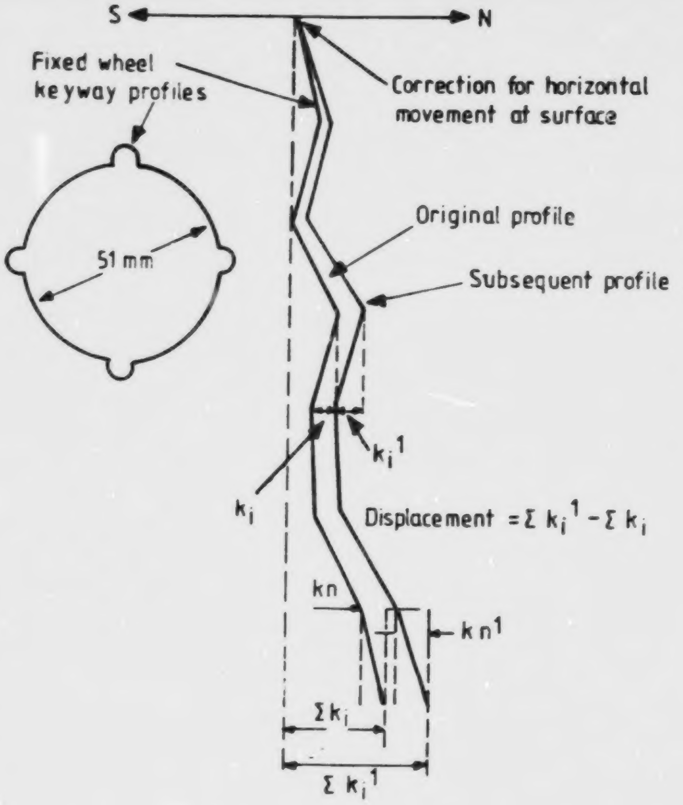
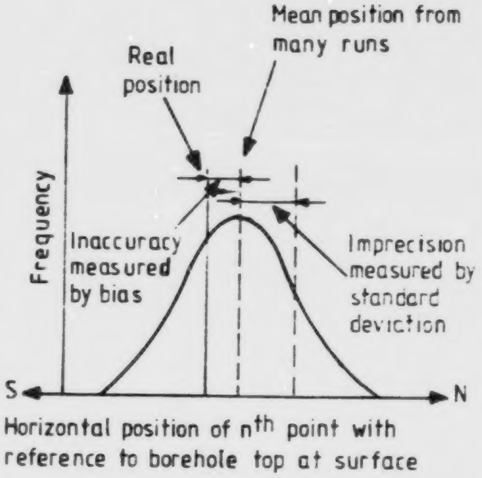
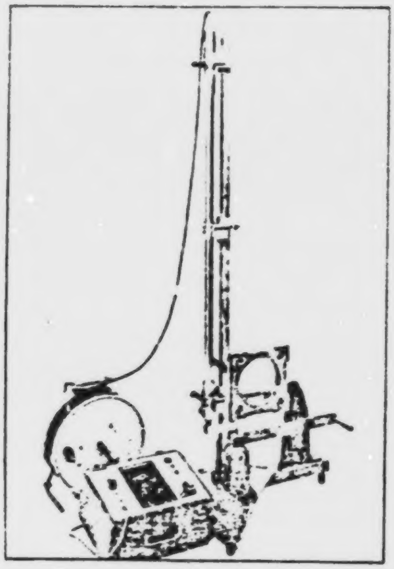
Figure [illegible]

INCLINOMETER AND ASSOCIATED EQUIPMENT
(After Hudson)
(Ref 4.125)


S
N
Fixed wheel keyway profiles
51 mm
Correction for horizontal movement at surface
Original profile
Subsequent profile
k_i
k_i^1
Displacement $= \Sigma k_i^1 - \Sigma k_i$
kn
kn^1
Σk_i
Σk_i^1





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The conclusions of a calibration study on this particular instrument are as follows:-

(i) The average error was within 0.2 mm for a 25 mm displacement measured over 1 m and within 1 mm for a 50 mm displacement measured over .15 m both at constant temperature.

(ii) A double run (180°) was sufficient to establish the position of the inclinometer tube to within ± 0.3 mm over a 5 m length; ± 0.8 mm over a 10 m length and ± 0.9 mm over a 15 m length, based on the data from the 34 measurement runs carried out.

(iii) An effect of up to 1 mm/m error per 23° C change of temperature was noted.

Other

Recent developments identified in the bibliography include two further techniques. Firstly, reference is made to a new (1979) laser-inclinometer with a liquid prism for use in subsidence monitoring in Germany. No details are available but this appears to have high potential for use in subsea monitoring (Ref 4.73). Secondly, an apparatus has been developed in Poland for the continuous monitoring of landslide surfaces. The system is used to detect and measure displacement of points during the initial and later phases of a landslide. The system utilises flexible connectors between points. The connectors are equipped with potentiometric transmitters which transform the relative displacement into electric pulses (Ref 4.72). Again, this system appears to have high potential for use in subsea monitoring.

Derivative Measurements

The great advantage of rock mechanics instrumentation is that it can easily be hooked up to continuous recording devices or be interrogated at any time via telemetry. Thus a continuous monitoring takes place. A weakness of any subsidence measuring system based on rock mechanics instrumentation, however, is that the instruments do not monitor directly the absolute ground movements and subsidence profile. This information must be derived and extrapolated from the local detections of, either strains when using strainmeters, or tilts when using tiltmeters. Nevertheless, a method based on rock mechanics instrumentation appears to be the only economical method for land-based telemetric monitoring of the subsidence.

Tiltmeters

There are several types of tiltmeters on the market. Based on physical operation principles, there are three basic types:-

(i) Electrolytic tiltmeters (called also electro-levels), which utilize the spirit level principle. The spirit level vial contains three electrodes linked in an AC energised wheatstone bridge type circuit.

(ii) Vertical pendula.

(iii) Accelerometers in which the electric output signal is proportional to the sine of the angle of tilt.

In all the above three types, the tilt is transduced into an electric signal with a typical voltage output of the range ± 5V. The resolution of the direct readout of the voltage output is typically 1 mV/10V = 0.0001 of the range of the tilt. Electrotype levels typically show a resolution of two seconds of arc over ± 0.7°.

There are many factors affecting the accuracy of tilt sensing, not just the resolution of the readout. A temperature change produces dimensional changes of the mechanical components, changes in the viscosity of liquid in the electrolevels and the damping oil in the pendulum type tiltmeters. Also the electrical characteristics change with the temperature. Drifts of tilt indications and fluctuations of the readout may also occur. For a price, most of the errors may also be compensated for, or their effect may be made linear thus allowing easy calibration. Some precision tiltmeters may cost US $20,000 or more.

In its subsidence research program in British Columbia, CANMET chose a "TERRA" tiltmeter consisting of two separate accelerometers with their sensing axes perpendicular to each other. The two accelerometers are encased in a vertical 25 cm long tube of 2.5 cm dia.

Figure 4.17, Ref 4.110, shows the installation design for the tiltmeters. The housing tube was designed to be cemented either directly into a borehole in the bedrock or to be fixed with five screws on the top of a brass base-plate equipped with three anchor bolts. Earlier use of electrolytic level for subsidence monitoring in the UK is shown in Figure 4.18, Ref 4.103).

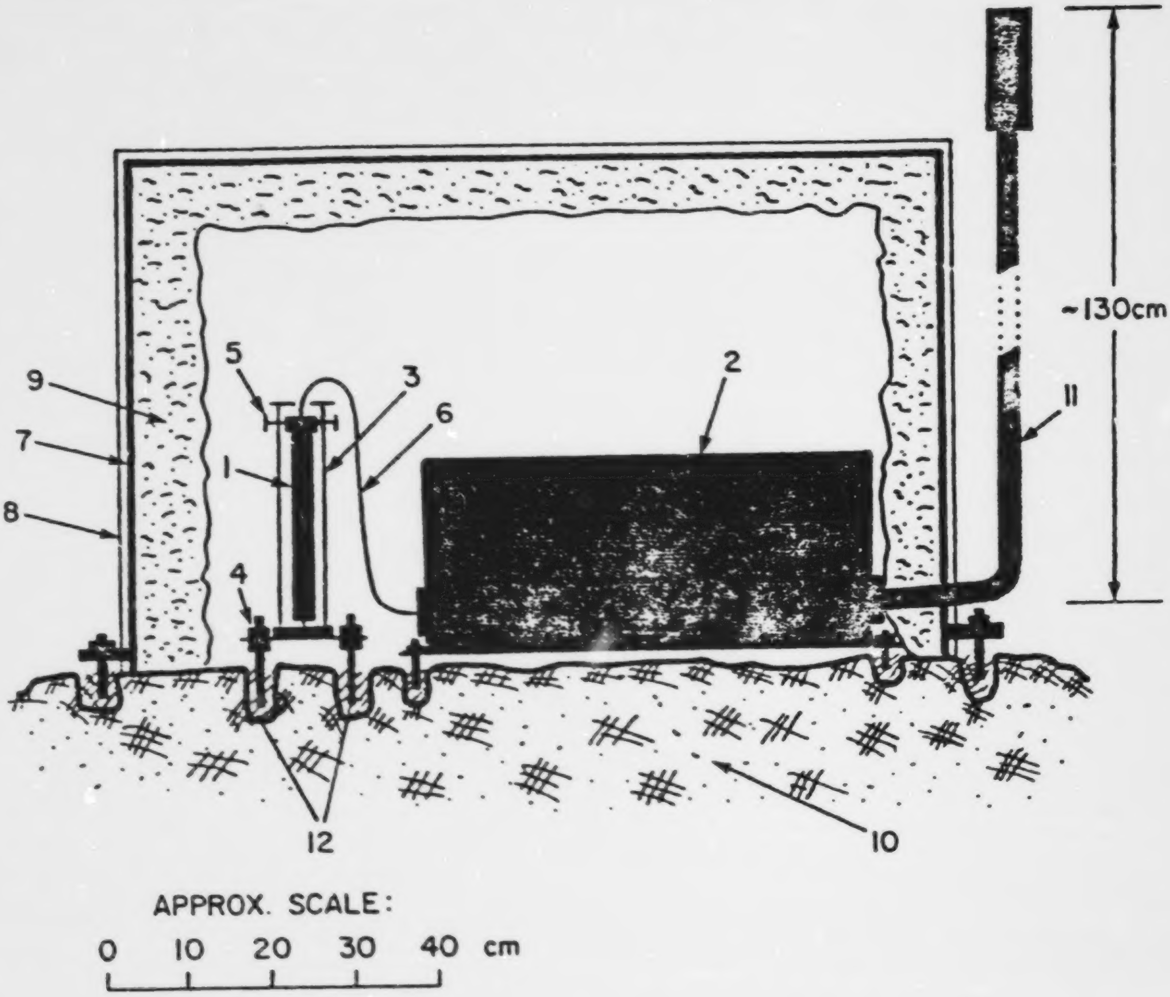
ADAS

An automatic data acquisition system (ADAS) used by Dames and Moore in conjunction with the US Department of Energy was used to monitor strain and tilt development as the face passed beneath the instrument house. One of the objectives of the ADAS monitoring program was to evaluate the subsidence characterization capability of a few (five), frequently monitored (bi-hourly), closely spaced (4.6 m) strategically located subsidence monuments. The data presented in a paper (Ref 4.30) are evidence that the maximum extension and contraction resulting from a travelling surface strain wave can be identified and quantified using ADAS.

The ADAS system is composed of a tilt measurement unit and linear displacement measurement unit. Both units use Transtek angular transducers. The transducers are connected to a 16 channel Datel data logger and are read hourly. Readings are recorded as voltages on a cassette tape in the datalogger. The transducers may be mounted on monuments or they may be mounted directly on the wall of a structure. The cassette data tape is fed directly into a computer where readings are converted to strain and tilt.

Figure 4.17

"TERRA" TILTMETER ARRANGEMENT
(After Fisekci et al)
(Ref 4.110)



~130cm
9
7
8
5
1
3
6
2
11
4
12
10
APPROX. SCALE:
0 10 20 30 40 cm

Layout of the field station

1 Tiltmeter
2 Slave unit
3 Housing of tiltmeter
4 Base-plate with coarse levelling screws
5 Fine levelling adjustment
6 Cable
7 Wooden case
8 Aluminum sheet
9 Fiberglass insulation
10 Bedrock
11 Antenna
12 Special grout

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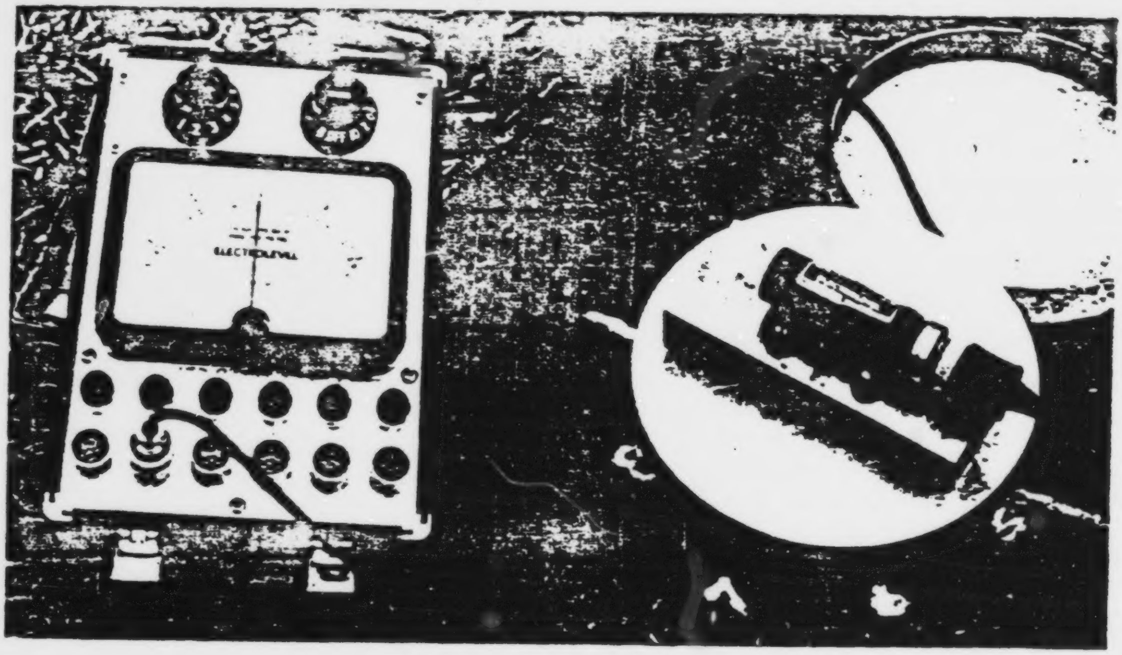
Figure 4.18

ELECTROLYTIC LEVEL FOR TILT MEASUREMENT
(after Forrester and Whittaker)
(Ref 4.103)



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The basic unit which assured the success of the ADAS was the DC input-DC output Angular Displacement Transducer (DC-DC ADT) which converted tilt angle and linear displacement into a DC voltage for recording. The DC-DC ADT is a precision differential capacitor coupled to a solid state oscillator, demodulator and amplifier to yield DC input - DC output performance. With a fixed DC voltage input (12 to 16 volts at 30 milliamps) these transducers deliver a high level analog DC voltage output directly proportional to shaft angular displacement with a high degree of conformity and infinite resolution, limited by the detecting equipment.

The detecting equipment consists of a battery operated, multi-channel, automatic recording digital voltmeter which includes a cassette data logger, a digital thermal printer and a liquid crystal display unit. The cassette data logger was to be used for storing data on magnetic tape for later reduction by a computer. This element failed soon after field installation. The digital thermal printer and the liquid crystal display were to be used for conveniently checking the equipment in the field but failure of the cassette data logger element resulted in the use of the printer as the primary field data recorder.

The sensitivity of the system for measuring tilt was 0.01, per millivolt. The tilt was sensed as an angular displacement between the monument on which a DC-DC ADT was mounted and a 3 kg (6.6 lb) pendulum suspended from the shaft of the DC-DC ADT. The sensitivity for measuring linear displacement between monuments was 8.9 x 10-3 mm (0.35 x 10 -3 inches) per millivolt. The linear displacement was sensed as an angular displacement of a pulley attached to the shaft of an ADT. The angular displacement was affected by the relative motion of one monument with respect to a second one through a stiff coupling of 0.5 mm (0.02 inch) dia invar wire. One end of the wire was firmly fixed to one monument while the other end was passed over a 100 mm (4 inch) dia pulley attached to the shaft of a DC-DC ADT which was mounted on the second monument. Constant tension in the invar wire was maintained by suspending a 3 kg weight on the end passing over the pulley. Overall system noise was approximately ± 2.5 millivolts peak-to-peak.

Future Developments

Geophysics

Seismic

Seismic methods make use of the fact that elastic waves travel at different velocities in different rocks and behave in certain ways when encountering interfaces between rocks. The principle is to initiate waves at a point and to determine at a number of other points, the time of arrival of seismic energy which has been refracted or reflected by the different rock formations.

Surface seismic techniques are now well developed for use in coal exploration. The results from surface seismic surveys are used in conjunction with data from boreholes and from surface and subsurface mapping. These provide a more complete picture of the subsurface geology to depths up to 1,500 m (10,000 m in oil exploration). The smallest features which can be resolved are faults with throws of 3 m at depths of 800 m.

The potential of seismic surveying in subsidence monitoring is threefold:-

(i) measurement of subsurface deformation from surface surveys,

(ii) measurement of subsurface acoustic events in the strata mass as a whole from surface surveys,

(iii) measurement of subsurface deformation between boreholes from downhole surveys.

In a subsea monitoring scheme, the potential seems high concerning provision of information on concentration of ground movement in the rock mass and its migration towards the surface. This is reviewed as follows:-

(i) Subsurface subsidence:

Unfortunately, the resolution required to detect deformation of marker horizons at depth, to fractions of a meter, is not available (Ref 4.104, L J Jackson) and five years ago it was believed unlikely that anything smaller than features of 3 m could be detected.

(ii) Strata Mass Deformation:

Seismometer networks over longwall panels in the UK have been used to record the location (to ± 50 m) and magnitude of seismic events in overlying strata. Although this was research into a specific problem where surface seismic tremors were being regularly felt by the general public and where the workings were under old workings, it is considered to have potential for monitoring concentration of movement in the strata mass, eg long crack planes/fault planes, etc. Analysis of results could identify areas of the seabed for closer examination for cracking and concentrating deformation.

(iii) Cross Borehole Survey:

In a paper presented in December 1981 (Ref 4.22, Albright et al) examined the potential of seismic transmission work between two boreholes to produce tomographic images illustrating the rock structure between the holes. The theory is that periodic borehole deformation surveys combined with cross hole seismic surveys would enable changes in rock structures to be detected, eg opening of joints, cracking or faulting of strata. Unfortunately, the optimum spacing of 10 m between boreholes would mean that this was very expensive (even to depths of only 200 m). It had not been tried in field trials at that time. However, if boreholes were to be instrumented for other purposes, trials of this technique between two boreholes 10 m apart situated in the zone of maximum tensile strain merits closer investigation.

A brief review of the opinion of various UK specialists on the current status of seismic surface surveys for use in subsea subsidence monitoring follows:-

(i) NCB Exploration Unit: accuracy of seismic would be inadequate for measuring the small defections in subsidence. Down-the-hole methods, usually a neutron log method using a sond, is carried out once only as it relies on a good borehole surface. Generally speaking the condition of the borehole lining has deteriorated to an unusable condition within a few days.

(ii) Marine geophysics has been used extensively for determining position of rock head and structure of strata and position of aquifers using seismic for borehole logging techniques. However, it would have no application in the measurment of subsidence strains or strata deformation, due to lack of sufficient resolution.

(iii) NCB Geophysics Unit: direct measurement of subsidence using geophysics has not been attempted in the UK. However, some assessment of the potential measurement of upwards bed separation has been carried out (see below).

(iv) Nottingham University Mining Department: seismic would have no application as accuracy is not great enough, as the investigators are looking for movements equivalent to seam thickness. Downhole logging using a sond and nuclear source is possible but unlikely as a borehole is usually logged once only. Thereafter hole deterioration causes rapid fall off in accuracy, particularly in mudstone. General speaking accuracy is measured in cm not mm, as may be required for subsidence monitoring.

(v) NCB Mining Research and Development Establishment: some tests were carried out at a large colliery in North Notts using in-seam seismic techniques to measure strata movements. Some success was achieved. There appears to be potential for adapting the principles to subsidence monitoring, but no "package" has yet been developed for routine measurement. However, NCB could provide further services of an advisory nature as required. Again doubts were expressed over any application of geophysics for monitoring strata deformation at seabed.

Micro-Gravity

The paper by Albright et al (Ref 4.22) discusses the potential for using sensitive gravimeters to detect anomalies in the gravity field at the surface caused by subsurface ground deformation from mining subsidence. Although this technique looks favourable for monitoring possible migration to the surface of large voids at shallow depths (100 m) eg old room and pillar workings, its use for subsidence monitoring appears restricted. This is due to the non-uniqueness of the gravity anomalies detected. A given gravity anomaly, for example, could result from a number or combination of non-mining related sources. In addition the mining related aspects such as void migration, bulking of strata and hydrologic disruption would also combine and be difficult to distinguish.

Resistivity

Mention is made in Ref 4.66 of the bibliography to a recent Polish development. This involves measurement of the electrical resistance of new surface rocks during undermining by a longwall face. In addition similar methods are used in detection of abandoned shafts in Poland. No details are readily available, although the potential of these systems for measurement of small subsidence deformation would seem limited.

Other Methods

Two recent developments in the field of underground gasification of coal may be of relevance (Refs 4.3 and 4.62) and are briefly mentioned.

(i) CSAMT: a controlled source audio-frequency magneto-telluric (CSAMT) technique is being developed for monitoring the underground process.

(ii) HFEM: high frequency electromagnetic (HFEM) scans are used for between-borehole surveys to detect cavities and zones of burning coal. Although details are not available, the potential of these CSAMT and HFEM systems for measurement of small subsidence deformations would seem limited.

(iii) Aerial Photogrammetry: another method used in Germany for detection of underground voids is that of aerial photogrammetry and in particular, infra-red scanning, in combination with surface thermography and photography (Ref 89). However, this would be inappropriate for subsea data collection.

(iv) "Cable break" finders or "Time Domain Reflectometry": US investigators have used this technique in surface boreholes to determine depth of breakers. It uses a cable cemented in a borehole as described by Wade and Conroy in their 1977 paper on a Rock Mechanics Study of a Longwall Panel to the American Society of Mining Engineers in St Louis, USA. Also the UK National Coal Board (NCB) have been examining methods of observing the speed of upward bed separation above longwall workings. The method proposed for development requires a borehole to be driven to within a few metres of the seam, before extraction, from above (either the surface or from old workings). The instrumentation simply requires a single electric cable to be cemented down the full length of the borehole. As subsidence occurs the cable would break off as bed separation occurs, the break point moving progressively and, upwards as extraction took place. The unbroken length of cable would be regularly measured using standard telecommunication industry "cable break finder" instrumentation. This utilises a high frequency AC pulse sent down the cable, which bounces off the break and returns. Travel time of the pulse is related to cable length. Hourly pulses would be recorded on a data logging system. However, this gives little absolute information indicating only the latest point at which breaks have occurred.

Geodetrics

Further development of total station electronic theodolites can be expected to be concentrated on refining the existing technology to make it more reliable, accurate and user-convenient. However, substantial development in the associated software can be envisaged. Again current developments would be expected to continue to improve speed, accuracy and plotting. Given the demand and research backing, this will include subsidence related software (profile plotting, etc).

Total stations have a definite role to play in subsea subsidence monitoring in one area, that of collection surveys between underground and surface. Their use would be cost-effective and produce quick accurate results.

Summary

The land based instrumentation systems are summarised in Table 4.3. Their potential for application for undersea use, must depend upon the environment that can be made available. For example, if water-tight, air conditioned galleries were feasible, then the land-based techniques could be adopted with little modification. If this were not so then the potential for encapsulating the instruments would be important. In particular, scope for electronic measurement, recording and even transmission of data to a remote monitoring station, would be of paramount importance. The use of optical survey techniques is of course limited by the surrounding media, ie they would be suitable surrounded by air but not submerged in seawater.

The following areas have been identified with potential for use in subsea monitoring:-

- air-conditioned galleries on the seabed over monitoring lines
- remote acquisition of data using land based techniques, eg total station and extensometer techniques
- remote operation/data acquisition of extensometer systems
- remote operation and use of inclinometer systems in horizontal tubes on the seabed
- ADAS system, suitably encapsulated, for tilt and strain measurements
- seabed mounted seismometer network for monitoring strata mass behaviour at depth
- in-seam seismics to "look up" and examine strata mass behaviour
- total station techniques in any underground to surface correlation surveys.

In Figure 4.19 an attempt has been made to illustrate the types of instrumentation system that could be adapted for seabed use, ranging from

TABLE 4.3

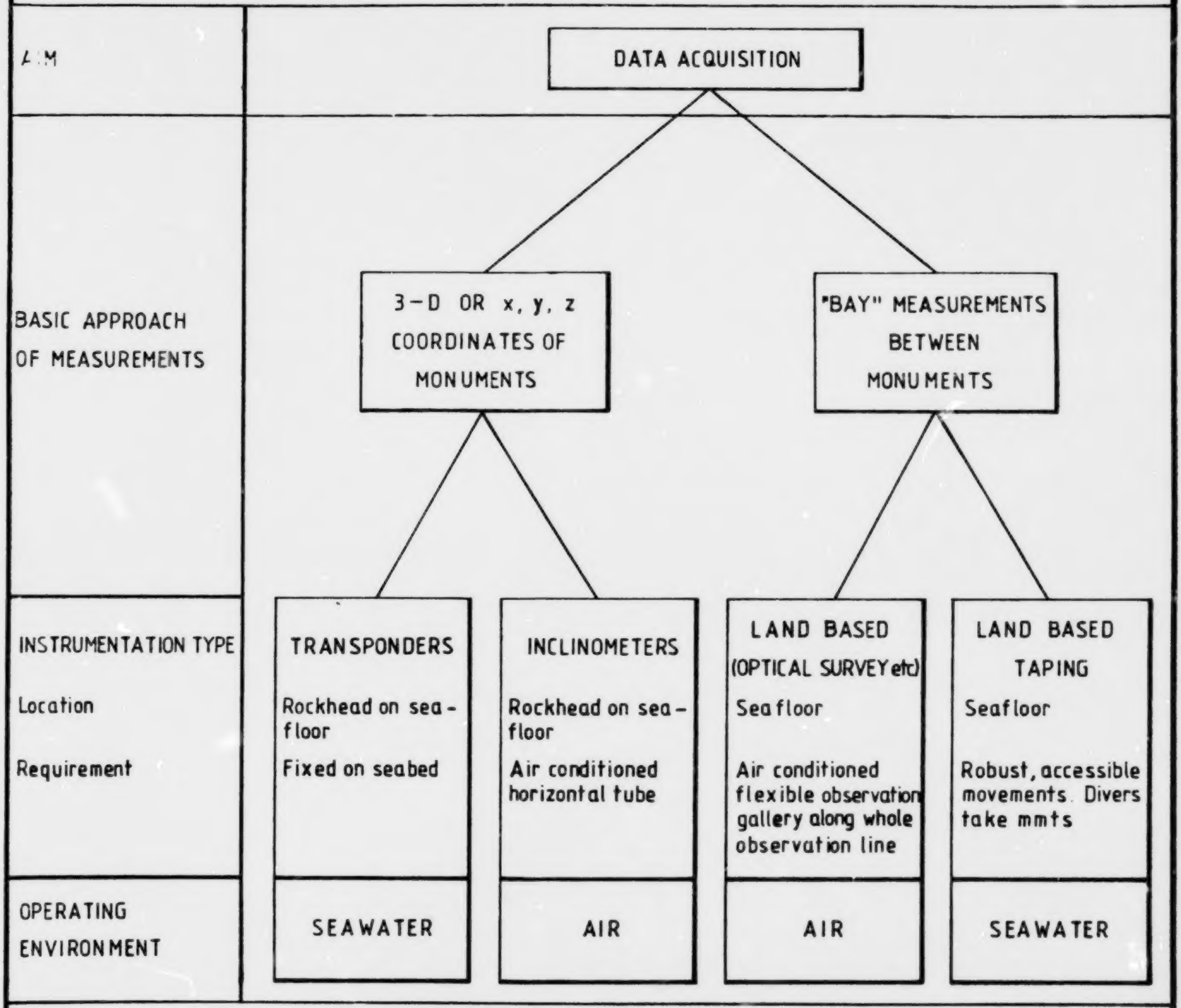
MEASUREMENT OF MINING SUBSIDENCE FROM LONGWALL MINING

METHODS AND TECHNIQUES AT THE SURFACE, LAND-BASED

Components of Ground Movement	Definition	Methods of Measurement	Measurement Techniques	Accuracy	Range (approx)	Comment
- VERTICAL SUBSIDENCE	- VERTICAL LOWERING OF THE GROUND SURFACE	- OPTICAL SURVEY LEVELLING from stable ground to subsidence monuments at periods during mining	- ENGINEERS LEVEL & STAFF	± 1.0 mm/km	3 m between points	Must refer to a stable reference monument and [illegible] measurement [illegible]
			- GEODETIC LEVEL & INVAR STAFF	± 0.1 mm/km	3 m between points	
		- SETTLEMENT GAUGES	- VARIOUS FLUID TYPES AS USED IN EARTH DAM MONITORING	± 2 mm	3 m between points	
		- LASER TECHNIQUES	- FOCUSING OF LASER LIGHT BEAMS ON GRADUATED SCREENS AT OBSERVATION POINTS		5 m - 1000 m	- Laser unit must be sited on stable ground [illegible] requires unobstructed sight lines
SLOPE OR TILT	- DIFFERENTIAL VERTICAL SUBSIDENCE BETWEEN TWO REFERENCE POINTS OR AT A POINT	- TILTMETERS	- ELECTROLYTIC LEVELS	} ± 0.2 mm/m		} Both require a secured reference surface at or fixed to monument
			- ACCELEROMETERS			
		- PENDULA				- Incorporated in USBM Automatic Data Acquisition System (ADAS)
		- DERIVATION FROM LEVEL & LENGTH MEASUREMENTS	- MANUAL OR COMPUTER AIDED CALCULATION			
- CURVATURE	- DIFFERENTIAL SLOPE	- DERIVATION FROM LEVEL & LENGTH MEASUREMENTS				
- SPATIAL DISPLACEMENT	- 3 OR 2 DIMENSIONAL DISPLACEMENT OF SUBSIDING POINTS	- OPTICAL SURVEY OBSERVATIONS	- TRIANGULATION			
			TRILATERATION	± 5 mm	5 m - 1000 m	
			- 2-D TRILATERATION PLUS LEVELLING			
			- "TOTAL STATION" INSTRUMENTS	Angular ± 1 second of arc Distance ± 5 mm + 5 ppm		
		INCLINOMETERS	- HORIZONTAL "MOLE" INCLINOMETERS	± 0.5 mm [illegible]	1 m - 15 m	
			- LASER INCLINOMETER			
		- POTENTIOMETRIC TRANSMITTERS	- FLEXIBLE CONNECTORS & REMOTE MONITORING BETWEEN FIXED POINTS			
- HORIZONTAL STRAINS	- DIFFERENTIAL DISPLACEMENT ie, change in distance ÷ original distance between 2 points	- TAPING	- LINEN OR STEEL TAPING OF DISTANCE PLUS CALCULATION			
		- EXTENSOMETERS	- VERNIER MEASUREMENT OF TAPE suitable for Electronic & Remote use	± 0.[illegible] mm	[illegible]	
		- WIRE-ANGULAR DISPLACEMENT TRANSDUCERS	- A FIXED WIRE BETWEEN 2 POINTS PASSES OVER A PULLEY; ROTATION IS MEASURED	± 0.5 mm		- As included in USBM ADAS
		- OPTICAL SURVEY SYSTEMS	- TACHEOMETER OR EDM SYSTEM	± 5 mm + 5 ppm	20 m to 2500 m	

Figure 4.19

POSSIBLE TYPES OF INSTRUMENTATION SYSTEM FOR MONITORING OF SEABED SUBSIDENCE


AIM
DATA ACQUISITION
BASIC APPROACH OF MEASUREMENTS
3-D OR x, y, z COORDINATES OF MONUMENTS
"BAY" MEASUREMENTS BETWEEN MONUMENTS
INSTRUMENTATION TYPE
Location
Requirement
TRANSPONDERS
Rockhead on sea-floor
Fixed on seabed
INCLINOMETERS
Rockhead on sea-floor
Air conditioned horizontal tube
LAND BASED (OPTICAL SURVEY etc)
Seafloor
Air conditioned flexible observation gallery along whole observation line
LAND BASED TAPING
Seafloor
Robust, accessible movements. Divers take mmts
OPERATING ENVIRONMENT
SEAWATER
AIR
AIR
SEAWATER

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divers reproducing land based measurements at one extreme to a total remote monitoring of seabed located instruments.

Design criteria for a seabed subsidence monitoring system have been outlined covering the following aspects: site; layout of observation stations, their design and spacing; instrumentation.

4.4 - ALTERNATIVE LAYOUTS FOR MONITORING MINING SUBSIDENCE

Introduction

The ideal layout for subsidence stations allows measurements to be taken to show the movement, both vertical and lateral, of any point at any time. This process is then repeated for other mine workings in order to establish values for a range of panel widths and seam depths, for panels in first, second and subsequent seams and for a variety of mining and geological conditions.

Care must be taken to ensure that field measurements are begun before the onset of subsidence and continued until all movement has ceased. Monitoring is also undertaken to determine the interaction of panels separated by narrow roadway protection pillars.

Such a programme would require many observations taken over a period of a number of years to establish complete prediction models for the undersea workings of Nova Scotia. Much of this information could, however, be inferred from previously observed European or other data perhaps with priority being given to the observation of strain values in order to meet the special needs of this case and determine the local strata deformation characteristics.

Layouts

A layout of subsidence stations necessary to obtain all the required data is shown in the attached figures; for this purpose a single panel has been divided into three zones:

Zone A - the area unaffected by the start or stop positions

Zone B - around the stop position

Zone C - that area around the start position of the panel.

The layout requires the siting of many observation stations, at the recommended spacing of 0.05 (1/20) times depth. A compromise may therefore have to be made between the amount of data acquired and the effort and expense of installing surveying observation stations. The layout of observation stations should, in any case, be tailored to the requirements of any particular mining layout and to the type of data required.

Figure 4.20 (1) shows the breakdown of the area in question into three zones and also the lateral movement of a typical point as the panel advances towards and then away from the point.

Alternative Layouts

Firstly, the simplest form of layout, namely a single line of monuments or stations, is discussed to illustrate the principal requirements of any monitoring scheme. Alternative layouts are presented and discussed.

Zone A

A single line of stations would suffice in a level seam, but with a dipping seam, advantage can be taken of the changes produced in width/depth ratio. These stations should be level with each other in order to obtain maximum subsidence and transverse profile shapes and surveyed by remote means to determine the absolute lateral movement of selected points. There should be a local network for establishing the movement of the remaining stations. These lines should be across the full transverse profile in order to establish the corrections to tensile strain on the rise and dip sides of the panel, see Figure 4.20 (2).

Zone B

Line x-y established above in Figure 4.20 (2), would also suffice for obtaining dynamic movement; line x-y is assumed to move relative to a fixed face position, see Figure 4.20 (3).

Any additional lines would need to be set out, as a check on the longitudinal dynamic profiles deduced from observing line x-y and for determining values for the stop profile, see Figure 4.20 (4).

Care should be taken to ensure that this line is sufficiently long to guard against premature stoppage or a prolonged "life" of the panel.

Zone C

The start position of a panel is the most difficult to monitor and ideally would be covered by a complete grid system, see Figure 4.20 (5).

In the event of the complete grid system being considered inappropriate, the minimum requirement would be single longitudinal and transverse lines. These could be supplemented by either additional, (shorter) transverse lines, established at suitable positions along the assumed start profile, or by any number of radial lines.

Further alternative layouts of observation stations have been used in the UK and have included:

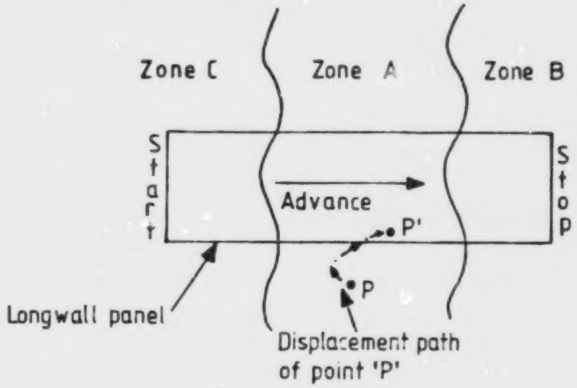
(i) Triangular Chain System

In this case strains have been measured along the sides of the triangles with principal strains being calculated and assumed to act

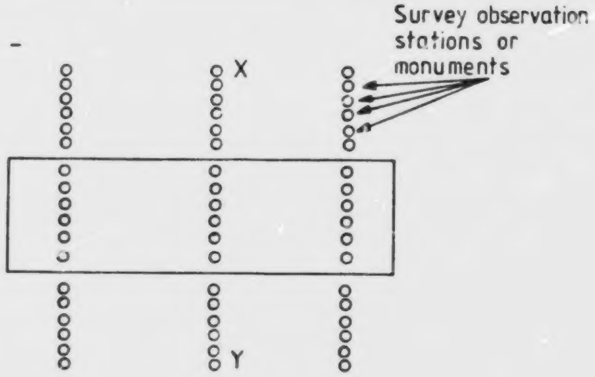
Figure 4-20

ALTERNATIVE LAYOUTS OF OBSERVATION STATIONS TO MEASURE SURFACE SUBSIDENCE FROM LONGWALL MINING

4.20(1) Zones over Longwall Panel


Zone C
Zone A
Zone B
Start
Stop
Advance
P'
P
Longwall panel
Displacement path of point 'P'

4.20(2) Transverse observation lines in each Zone


Survey observation stations or monuments
X
Y

4.20(3) Transverse line in Zone A only

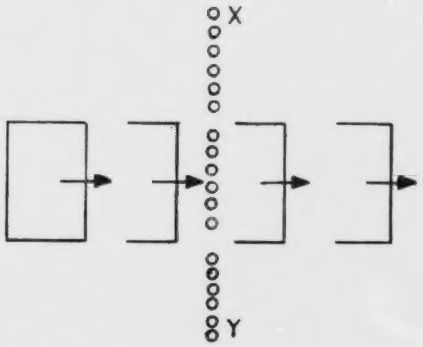


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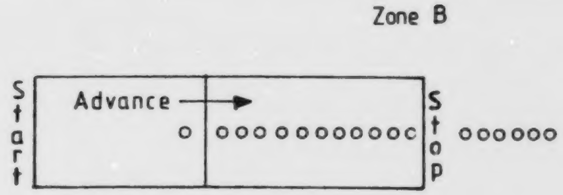
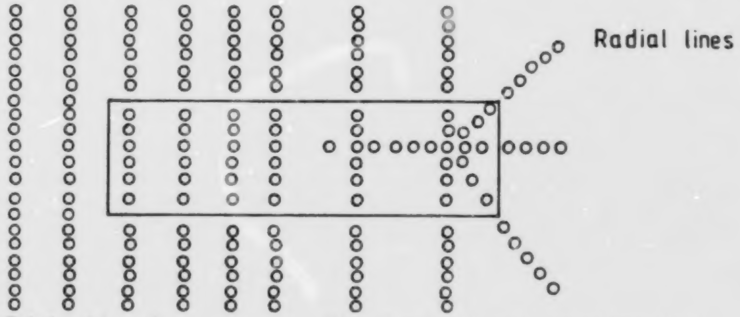
Figure 4.20(Continued)

ALTERNATIVE LAYOUTS OF OBSERVATION STATIONS TO MEASURE SURFACE SUBSIDENCE FROM LONGWALL MINING

4.20(4) longitudinal observation lines



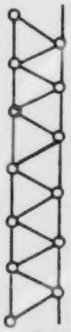
4.20(5) Two multi-line layouts



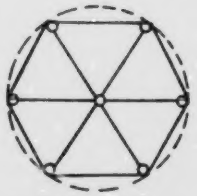
5a) Total grid system

5b) Single lines supplemented by 2 radial lines

4.20(6) Other layouts



6a) Chain system



6b) Rosette system

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upon the centre of each triangle. This system is preferable to a single line of observation stations where only strain, and not absolute movement, is being recorded. Not only does it enable absolute movement to be measured, it provides a more complete and comprehensive data base for analysis. In addition, it is more robust to overcome the effects of losing a monument during observation, for whatever reason, see Figure 4.20 (6a).

(ii) Rosette System

This is a useful system which quite clearly demonstrates the importance of surface direction when considering strain, see Figure 4.20 (6b).

(iii) Isolated Stations

A small number of stations measuring tilt and strain accurately eg Automatic Data Acquisition System. However, although this may provide suitable data for a prediction model it would be most limited in monitoring seabed behaviour as a whole.

In summary, it should be restated that observation systems should be designed for the specific requirements and conditions of each individual case.

4.5 - DESIGN CRITERIA

Criteria

The following design criteria are recommended for a seabed subsidence monitoring program.

Monitoring Site

- should cover full extent of movement from at least two adjacent panels in the same seam
- seabed area should be free of sediment problems and unstable ground conditions such as sediment instability and drift which could affect stations
- relatively large amounts of subsidence are required for early testing of seabed monitoring systems
- must be correlated to underground survey to appropriate accuracy.

Layout of Stations (see Section 4.4)

- should include reference stations or monuments on stable ground away from mining
- the relative position to underground workings is crucial and should extend from stable ground over the panel(s) in both longitudinal and transverse directions

- should include additional stations in 45° lines over start/stop positions of panel plus extra stations in zones of tensile strain
- should adopt triangle chain network especially in zones of tensile strain
- should be capable of detecting concentrations of ground movement (eg surface cracking, where possible).

Design of Stations

- all stations should be permanently fixed to rockhead (solid rock) to avoid anomalous movement
- all stations should be close to the rockhead surface (to avoid misleading data and to avoid exposure to damage)
- all stations must enable precisely the same point to be measured on each occasion.

Spacing of Stations

- preferred spacing is 0.05 x depth from seam to seabed
- maximum spacing is 0.1 x depth from seam to seabed

Observations and Accuracy

- station co-ordinates (xyz) should be measured as precisely as possible (eg, ± 1 mm)
- distance between stations should be measured to within a maximum of ± 10 mm or to better than 1 in 10,000 whichever is the smaller
- acceptable closure errors in land based levelling traverses = 1 in 5,000
- should include crack detection and mapping and theodolite angle traverses.

Observation Frequency

- at least two surveys of station layout before mining commences (for calibration of instrumentation and to ensure original positions are known)
- periodic station layout surveys during mining, preferably at intervals of panel advance = 1/20 x depth, 1/10 x depth maximum
- supplementary layout surveys during the passage of the panel beneath the stations to ensure transitional tension zone is detected

- ad hoc measurements taken in areas where unusual or concentration of movement is occurring, as required.

Observation Procedures

- scientific measurement procedures must be adopted (to appropriate international standards)
- details of all calibrations of equipment must be kept
- use of standard/approved instrumentation measurement procedures and data recording
- incorporation of cross-checks in data collection, with immediate re-measurement if required accuracy has not been attained.

Observation Data Analysis and Presentation

- details of actual measurements taken in each survey
- calculation of vertical subsidence profiles along observation lines
- derivation of tilt and tilt profiles from vertical subsidence
- calculation of horizontal displacements and profiles
- derivation of differential horizontal displacement strains and both compressive and tensile strain profiles
- processing of "triangle" strains to determine magnitude and direction of principal strains
- all profiles should be presented showing relationship of panel position (projected to the seabed, normal to the dip of the seam)
- adoption of suitable computerised 3-D graphical presentation.

Instrumentation

- should be robust to all effects of the operating environment
- should be capable of detecting the smallest acceptable change in the variable required
- should cover the full range of variation expected
- should consistently reproduce the measurement to within the required accuracy
- should be reliable in operation
- should provide data in suitable form for subsequent analysis.

Summary

Subsidence data collection is a costly and risky business. A substantial investment is needed (even for land based measurement) to:-

- provide the optimum combination of suitable, reliable and accurate instruments
- design and install permanent reference points across the area of movement
- observe regularly and comprehensively, the positions of the stations and to calculate, derive and present the subsidence parameters/profiles etc.

When all that has been done, and if all has gone well, the achievement comprises at best a partial picture of the 3-D deformation of the surface, over a single mine working for a single set of unique geological circumstances.

In addition, the reliability and usefulness of these data are reduced if:-

- the observations were not taken before mining started to affect stations
- any stations or instruments have failed or been damaged
- any of the periodic sets of observations were delayed or missed
- the mine working alters from that planned (eg in location, extent or rate of advance).

Very close collaboration and co-operation between researchers, observers and mine operators are required throughout. In addition very high, scientific standards of measurement and analysis are required if the results are to be meaningful.

It can be seen that the path of subsidence research is a somewhat daunting one. It is paved with frustrations and complications and, even if 100% successful, provides only a small piece of information out of a very large tapestry of ground deformation. Many such observations from different workings covering a range of width/depth ratios are required to start the picture. It is important to the success of any seabed subsidence monitoring system that these aspects be thoroughly understood at the outset. In this way the possible pitfalls associated with routine monitoring can be avoided and efforts concentrated on meeting the challenge provided by overcoming the unique environment of the sea floor. Finally, the cost investment involved in obtaining data must be viewed in the context of improved extraction (and hence income to mine operators).

4.6 - ROCK MASS DEFORMATION MONITORING

Introduction

The deformation of the overlying rock mass due to coal extraction is a complex summation of varying strains. These are dependent on the relative proximity to the created void and the physical properties of the various rock types. The cumulative strain throughout the rock mass is expressed as subsidence at surface (seabed) including local areas of extension or contraction. These surface phenomena are of paramount importance to the deformation of surface structures, but tell us very little about the changes in integrity (permeability) of the rock mass between the seabed and the mining horizon.

It is the integrity of this rock mass that is of great concern in the Sydney Coalfield. Current practice for total extraction is to use a ratio of 1:100, coal to overlying bedrock thickness. This has proved to be eminently safe as the rock mass integrity has been maintained. However, the safety factor implied in this practice is not known, nor what coal reserves are sterilized unduly.

One means of supplementing the surface-related subsidence measurements on the seabed would be to incorporate a parallel study to monitor rock mass deformation from within the strata between the mining horizon and the seabed. A study of this type was carried out between 1974 and 1976 in the Smoky River Coalfield (Bielenstein, Wright and Mikalson, 1977; see Appendix 4.1) and also between 1978 and 1982 at Lynemouth and Ellington Collieries under the North Sea off NE England (Styler and Dunham 1982, see Appendix 4.2). In both studies intrumentation was installed in a seam up to 150 m vertically above the main seam being worked by room and pillar. The purpose of these studies was to monitor the stability of a roadway containing a major conveyor belt installation. The results showed that strata deformation due to undermining can be monitored successfully from within that rock mass, in particular in offshore coalfields.

An approach to rock mass deformation monitoring for the Sydney Coalfield is outlined in the following paragraphs on access and data collection.

Access

In order to install instrumentation to monitor rock mass deformation, access must be provided above the mining horizon. This could be from existing workings (eg Harbour Seam for Lingan Phalen Mine) or from new roadways driven for instrumentation purposes. Initial access should be provided perpendicular to the longwall panels, crossing the mid-point of a number of panels. Additional headings could be driven above and parallel to selected longwall panels.

Based on the experience at Smoky River, a minimum stratigraphic interval of 100 m should be left between the instrumentation roadways and the roof of the mining horizon. Installing instrumentation at varying heights above the mining horizon would enhance the extrapolation of the results to the seabed. This could be achieved by driving a level instrumentation heading parallel to the dip direction of the seam. Assuming a 10° dip and 250 m between longwall centre lines, the increase in the strata interval for successive panels would be 44 m.

The instrumentation headings would have to be prepared well in advance of longwall mining and would require services to operate diamond drills.

Data Collection

The data required to analyse rock mass deformation would be obtained from permanently installed instruments, periodic surveys and visual observations. The following could be included in the total data package.

Precise Optical Surveys

Repeated surveys of established benchmarks would define the 3-D movement of these points relative to the progressive longwall mining below. This would provide the transitional deformation during mining and the final subsidence profile. The angle of influence (ie draw) would be established and would be available for multi-seam mine planning.

Seismic Surveys

Seismic surveys should be carried out both before and after mining to evaluate the change in rock mass integrity (reduction in velocity). This should be done for the strata above the instrumentation roadways to the seabed and below to the mining horizon.

Drillholes

Core should be obtained from drillholes down to the mining horizon. This would establish the strata succession and rock type variation. Standard geophysical logs should be run if permissible. The core should be tested for compressive and tensile strength, Young's Modulus and Poisson's Ratio should be used to quantify the physical parameters of the strata.

Sonic Logs

If possible sonic logs should be run in the drillholes. This would provide the data to produce synthetic seismograms for the rock mass.

Multi-wire Extensometers

Extensometers should be installed in down holes to monitor caving characteristics versus flexural deformation above the goaf.

Shear Strips

At Smoky River down holes were sheared off due to bedding plane slip during subsidence. Wire extensometers could be used to determine the remaining length of free wire by varying the tension applied to each wire. It would be prudent to install shear strips in some drillholes to monitor deformation in the plane of bedding.

Load Cells

Rock pressure changes should be monitored by installing load cells in horizontal drillholes (eg vibrating wire load cells). These instruments are very sensitive to pressure changes and would delineate the onset of subsidence well in advance of physical deformation. In addition this could provide information for the design of multi-seam workings.

Roadway Closure

Monitoring roadway closure is necessary to assess the effects of the rock mass in the immediate vicinity of the instrumentation roadway. Closure can be monitored by vertical and transverse convergence measurements. Continuously recording convergence rods should routinely be part of the instrumentation package, as they can provide a record of the rate of deformation (sudden movements are not averaged over the time interval between readings). These could be supplemented by repeated photographic records of the roadway periphery.

Interburden Strata Permeability Changes

Recent work in this field is discussed by Singh and Kendarski (1981) and by Neate and Whittaker 1979 Refs 125 and 123 involving various water measurement and use of vertical wire extensometers.

Discussion

Ground movement due to coal extraction comprises incremental rock mass deformation and subsequent surface/seabed subsidence. The surface deformation can have a serious impact on terrain or surface structures in developed areas. In under-sea mining, however, seabed deformation is of little concern; the real problem is the change in rock mass integrity and the potential hazard to the mining operation.

Rock mass deformation can be successfully monitored from within the rock mass, be it from existing workings or from roadways driven for this purpose. Once access has been established, currently known instrumentation and monitoring systems can be readily supplemented or adapted to accommodate site specific needs.

Multi-seam workings are planned for the Sydney Coalfield. The stress concentrations created by this mining system are largely dependent on local conditions. Monitoring from within the rock mass gives the opportunity for a realistic assessment of the design criteria for multiple seam mining. There may be opportunities in future mining plans to utilise old mine roadways in an upper seam to monitor subsidence and strata mass deformation being caused by mining in a lower seam.

4.7 - LITERATURE REVIEW : BIBLIOGRAPHY

Introduction

A literature search has been carried out by the International Energy Agency Coal Research Technical Information Service. Two subject areas were covered:-

(i) ground subsidence in undersea workings, (listed A-E in the bibliography)

(ii) monitoring of ground subsidence, including instrumentation (listed 1-126 in the bibliography).

These cover the last five to six years.

Details including brief abstracts are listed in the bilbiography, grouped under headings relating to the section and sub-section headings of the report. A brief resume of relevant content is given below.

Additional key references have been included for completeness.

Review of References

It can be seen from the index to the bibliography, that the literature search has been quite comprehensive. Aspects of current practice in monitoring mining subsidence are covered in the following countries:-

- United Kingdom
- United States of America
- Canada
- Australia
- South Africa
- Japan
- France
- Germany
- Poland
- Russia
- Yugoslavia
- China
- India.

Further supporting and supplementary references are listed for each of the major subsections of the report.

5.0 DIRECT MONITORING INSTRUMENTATION

5.1 Introduction

One of the criterion governing the extraction of coal from subsea mines is surface or seafloor tensile strain. The National Coal Board in the U.K. has, on the basis of past experience, established the limiting tensile strain at 10 mm/m. In the Cape Breton coal fields, where subsea longwall coal mining has been carried out successfully for many years, the limiting tensile strain (calculated) is set at 8.5 mm/m. The strains are estimated using procedures similar to those developed by the National Coal Board and outlined in the NCB Subsidence Engineers Handbook.

As discussed in the previous section, surface or seafloor subsidence gives rise to vertical and horizontal movements, and changes in slope or tilt at a given point within the zone influenced by mining operations. Surface strains are calculated using the measured changes in horizontal distance between adjacent surface points or they can be derived from the settlement or subsidence profile. Changes in slope and tilt may be measured directly or derived from the surface settlements.

Subsidence monitoring involves the measurement of vertical and horizontal movements and changes in slope and tilt. Land based monitoring programs usually include the measurement of surface settlement, horizontal strains, surface tilt and in some cases, subsurface vertical and horizontal deformations. Changes in slope are derived from the settlement profile. In addition a visual survey of the ground surface is undertaken to locate any cracks which may be visible at the surface.

The monitoring of seafloor subsidence obviously will be more difficult because of access and any monitoring program will need to have some built in redundancy both in the number and type of measurement systems. The instrumentation to be used in the program will permit the measurement of vertical and horizontal movements, slope, and tilt.

5.2 Magnitude of Movements

Current coal mining activites in the Sydney Coal field includes the Lingan Mine extracting 2 m of coal at a depth of 500 m below seabed at a distance of 4 km offshore, the Prince Mine extracting 2 m of coal at a depth of 190 m below seabed at a distance of 2 km offshore, and No. 26 Mine extracting 2 m of coal at a depth of 700 m below seabed at a distance of 7 km offshore. Panel widths as shown on the mine plans are variable with the most recently worked panels having approximate widths as shown below.

Mine	Panel Width (m) Approximate
No. 26	230
Lingan	230
Prince	120

The coal seams dip towards the offshore at angles of 5.6° (Lingan), 3° (Prince), and 9° (No. 26).

On the basis of the above mine dimensions, (depth, panel width, and seam thickness) the maximum movements, strains, and slopes estimated using the Subsidence Engineers Handbook (NCB) are as tabulated below.

				Maximum Estimated		
Mine	Depth (m)	Panel Width (m)	Seam Thickness (m)	Subsidence (m)	Tensile Straim (mm/m)	Slope
No. 26	700	230	2	0.4	0.4	1:550
Lingan	500	230	2	0.7	1.2	1:200
Prince	200	120	2	0.9	3.7	1:60

The maximum calculated subsidence or settlement, as well as tensile strain and slope changes, may be larger depending upon the panel widths actually developed in the mine. A maximum calculated tensile strain of 8.5 mm/m is permitted so panel widths may be wider than those shown at the present stage of mine development. However, the above values give a reasonable estimate of the magnitude of movements that wil need to be monitored.

5.3 Accuracy of Measurements

The design criteria as outlined in Section 4 specifies that the coordinates of a measurement point should be measured as precisely as possible (e.g. ± 1 mm), and that the distance between points should be measured to within a maximum of ± 10 mm or to better than 1 in 5000 whichever is the smaller.

A paper by O'Rourke, et al (1978), based on a research project sponsored by the U.S. Bureau of Mines, describes instrumentation systems for the measurement of on land mining subsidence, and outlines the level of accuracy considered to be necessary for such measurements. Second or third order levels of accuracy are suggested for vertical movements, while from ground surface horizontal strain an accuracy of 0.01 percent of the spacing of measurement point is recommended. These recommended standards are similar to the standards of accuracy included in the design criteria outlined in Section 4.

A summary of the levels of accuracy suggested for the subsidence monitoring program are as given in the following table.

Measurement	Range	Accuracy
Vertical Movement	0 to 1 m or more	±1mm second order
Horizontal Movement	0 to 1 m	±1mm or ± 0.01% of station spacing
Surface Tilt (slope)	<2°	± 30 sec.
Sub-surface Horizontal Deformation	<5°	± 30 sec

5.4 Layout and Spacing of Measurement Stations

In order to monitor subsidence resulting from the longwall mining operations, the seafloor movements will need to be monitoring along lines parallel to the direction of the face advance (transverse), and at a right angle to the direction of advance, i.e. parallel to the face. (longitudinal).

The design criteria presented in Section 4.5 and Figure 4-20 indicates that the measurement stations should extend from stable ground over the panels in both the longitudinal and transverse directions, and in addition should include stations in 45° lines over start/stop positions of the panel plus extra stations in zones of tensile strain. A triangular chain network is recommended in zones of tensile strain.

The spacing of measurement points is specified as:

- preferred spacing = 0.05 x depth from seam to seabed
- maximum spacing = 0.10 x depth from seam to seabed

The measurement station spacings are as recommended by the National Coal Board in the Subsidence Engineers Handbook. Other researchers (eg. Hood, et al, 1983) suggest that these station spacings are reasonable for the monitoring of subsidence. For the Sydney coalfield the recommended measurement station spacings are tabulated below:

Mine	Preferred Station Spacing (m).	Maximum Station Spacing (m)
No. 26	35	70
Lingan	25	50
Prince	9.5	19

Transverse Monitoring Stations

The limit of transverse subsidence as calculated by the NCB method for each of the mines is shown in the following table.

Mine	Depth (h) Metres	Panel Width (w) Metres	Ratio w/h	Limit of Subsidence Depth (d/h)	d* Metres
No. 26	700	230	0.33	0.86	600
Lingan	500	230	0.46	0.93	465
Prince	190	120	0.63	1.02	195

* distance from centre of panel to limit of subsidence.

On the basis of the above, the measurement stations for the Lingan Mine, for example, would need to extend some 465 metres to measure one half of the full transverse subsidence profile, and would need to extend beyond this distance to reach stable ground. Thus at least 20 stations for each transverse line would need to be installed when the preferred station spacing is adopted. Additional stations would be needed to complete strain triangles at selected locations along the measurement line. O'Rourke et al (1978) recommend 5 to 10 strain triangles per panel.

The number of stations required for a transverse line to monitor one-half of the full subsidence profile is shown for each mine in the following table. In estimating the number of stations allowance is made for five (5) strain triangles, and one reference station beyond the limit of subsidence.

Mine	Number of Stations (Transverse) Preferred Spacing = 0.05 x depth (h)
No. 26	24
Lingan	26
Prince	26

Longitudinal Monitoring Stations

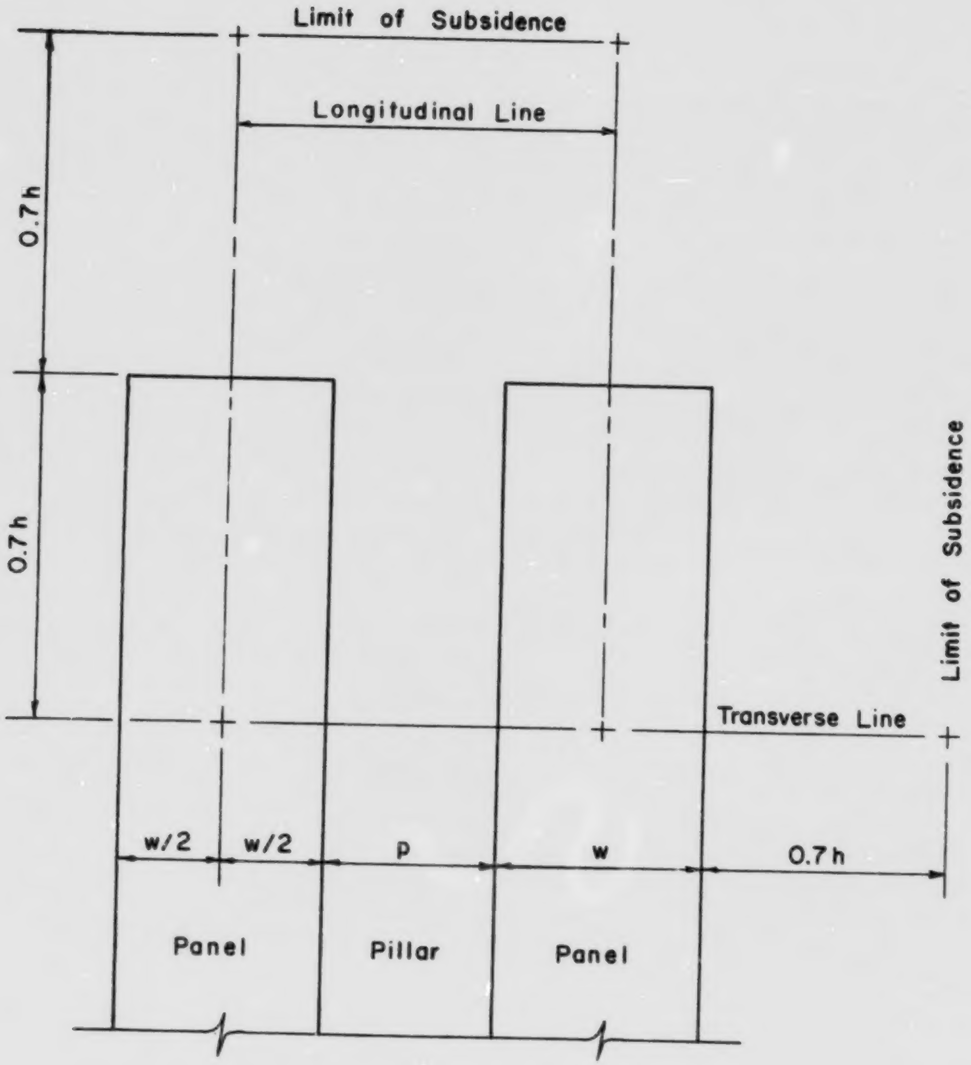
Along a line parallel to the direction of the face advance, the maximum subsidence occurs at a point when the face has advanced a distance of about 0.7 x h (h = depth of seam) beyond the point, and the subsidence trough extends for a distance of at least 0.7 x h beyond the face. Thus, longitudinal measurement lines would need to be of the order of 1.4 h in length. For No. 26, Lingan and Prince Mines this implies lengths of 980 m, 700 m and 220 m, respectively. The number of measurement stations required using the preferred spacing, and allowing for five (5) strain triangles and one reference station is as shown in the following table:

Mine	Number of Stations (longitudinal) Preferred Spacing = 0.05 x h
No. 26	35
Lingan	35
Prince	34

Monitoring Site

The design criteria developed for the seabed subsidence monitoring program in Section 4 recommends that the monitoring site covers the full extent of movement from at least two adjacent panels. This requirement will influence the number of stations along transverse lines but will not change the number of stations for each longitudinal line. The layout and length of measurement lines to cover two adjacent panels is shown in Figure 5-1. The total number of measurement stations required to monitor the movements for each of the mines is summarized in the following table. Allowance is made for one reference station and five strain triangles for each line.

	Number of Stations using Preferred Spacing	
Mine	Transverse	Longitudinal (two lines)
No. 26	34	70
Lingan	40	70
Prince	45	68


Limit of Subsidence
Longitudinal Line
0.7h
0.7h
Limit of Subsidence
Transverse Line
w/2
w/2
p
w
0.7h
Panel
Pillar
Panel

MINE	w (m)	h (m)	p (m)
No. 26	230	700	100
Lingan	230	500	90
Prince	120	190	60

FIGURE 5-1 THE LAYOUT AND LENGTH OF MEASUREMENT LINES TO COVER TWO ADJACENT PANELS

The layout of the measurement stations on the seabed relative to the location of the panel will be affected by the angle of dip of the coal seam. The surface subsidence trough tends to be offset towards the downdip side of the panel and the magnitude of this offset may be estimated using the procedures outlined in the NCB Subsidence Engineers Handbook (1975). Angles of dip at the No. 26, Lingan, and Prince Mines range from about 3° at Prince to 9° at No. 26.

The layout of stations discussed in the preceeding paragraphs is similar to that which has been employed for land based surveys where, in general, access has not been difficult and traditional precise surveying techniques are possible. In the case of subsea surveys, however, access is a problem and remotely operated measurement systems will be required. Thus, any arrangement of measurement stations which would reduce their number and yet provide information from which the subsidence and strain profiles can be obtained, would be desirable.

A possible layout which would reduce the number of stations, is one in which clusters of stations are installed along each of the measurement lines. Such a layout is shown in Figures 5-2(a) and 5-2(b). Six stations would be required for each cluster having a layout as shown in Figure 5-2(b),and a total of 48 stations would be required for the clusters shown in Figure 5-2(a), which is considerably fewer than for a conventional arrangement of stations.

5.5 Instrumentation

The design criteria for the instrumentation are given in Section 4 and are restated below:

(a) should be robust to all effects of the operating environment.
(b) should be capable of detecting the smallest acceptable change in the variable required (The standard of accuracy specified is second and/or third order)
(c) should cover the full range of variation expected

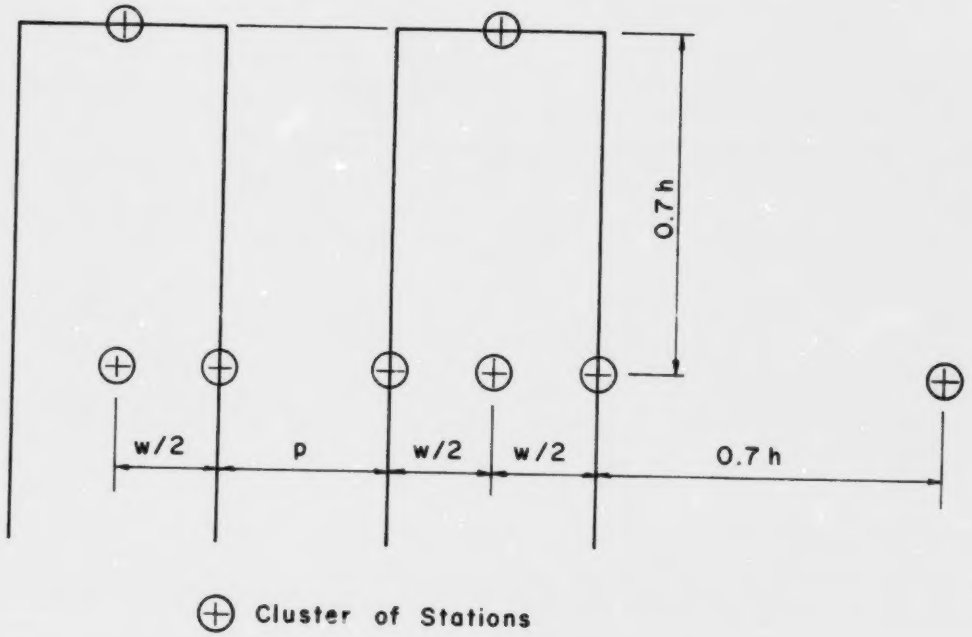

0.7 h
w/2
p
w/2
w/2
0.7 h
Cluster of Stations

FIGURE 5-2(a) POSSIBLE LAYOUT OF STATION CLUSTERS

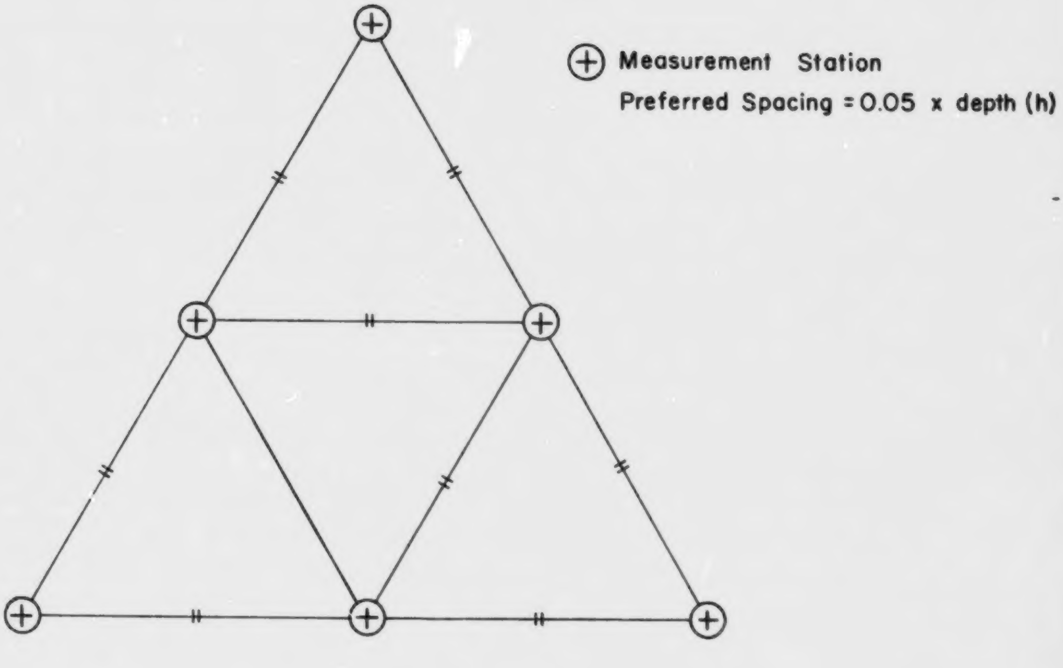

Measurement Station
Preferred Spacing = 0.05 x depth (h)

FIGURE 5-2(b) TYPICAL CLUSTER OF MEASUREMENT STATIONS

(d) should consistently reproduce the measurement to within the required accuracy (second or third order)
(e) should be reliable in operation
(f) should provide data in suitable form for subsequent data analysis

The instrumentation should be capable of remote operation, and the output signals must be such as to permit on-site storage and/or transmission to a control centre on demand.

Conventional on-land surveys designed to monitor subsidence utilize: precision levels for vertical settlement measurements, steel tape extensometers for distance measurements and the measurement of horizontal strains, precision levels and steel tape extensometers for the determination of tilt, or the use of tiltmeters, e.g. electrolevel tiltmeters, and horizontal inclinometers for the measurement of settlement or slope changes. For subsea monitoring the use of precision levels and manual steel tape extensometers is not feasible and other remotely operated instrumentation will be required.

In civil engineering and mining engineering practice several instruments have been developed to monitor:

(a) settlement of structures and embankments;
(b) subsurface vertical and horizontal ground movements;
(c) horizontal strains, particulary beneath and within embankments and earth dams; and
(d) tilt of structures and ground surface tilt

Such instrumentation are available commercially from manufacturers such as Sinco, Petur, Terrametrics, Geonor, Solinst, and others. The instruments have been developed primarily for on-land use and data collection has been of a conventional nature. Control stations have all been on land and accessible. Utilization of such instruments for subsea monitoring of subsidence will probably require some modifications and development.

Vertical Movements or Settlement: Settlement gauges have been used extensively in geotechnical applications and several models are listed below.

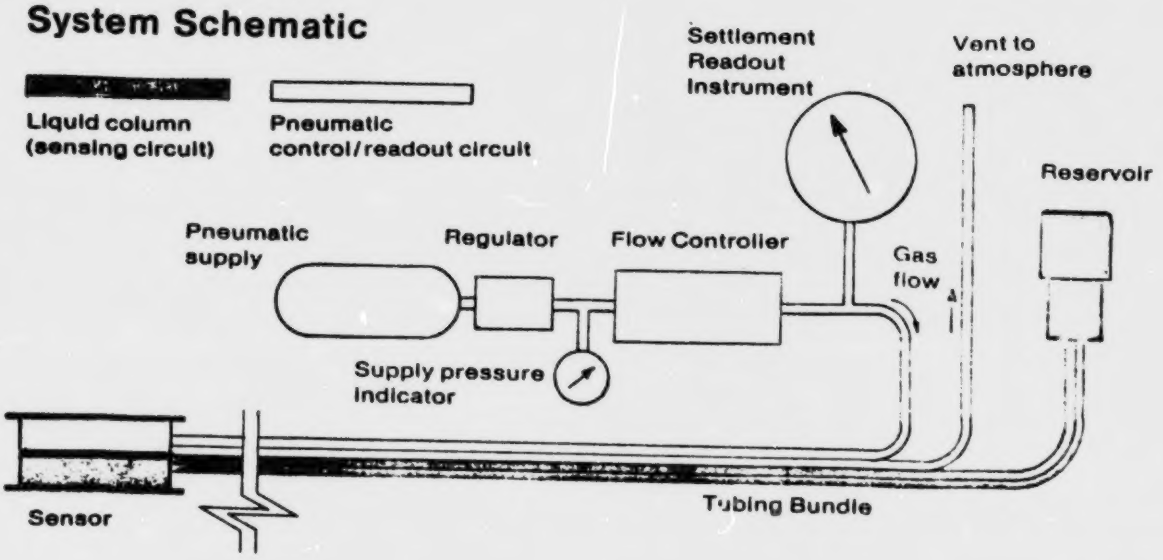
Type	Model No	Range (m)	Accuracy (mm)
Petur	SS106	3.20	± 3
	SS107	7.10	± 6
	SS108	10.88	± 15
Sinco	51483	1 - 6	± 3.2
	514163	3 - 76	± 6.4
	52683	0.450-7.60	± 2.5
Solinst	Pneumatic Settlement Cell	2	± 10

The instruments operate on the principle of balancing a pressure across a diaphram as illustrated by Figure 5-3. Once installed, any vertical movement is reflected by a change in fluid pressure in the sensor. The sensor pressure measurement is made by applying increasing gas pressure until flow is achieved, which indicates a balanced system. A similar system employs a vibrating wire strain gauge to indicate a balance point. Suppliers suggest that these systems may be adopted for automatic and continuous operations. Adaption for use within the marine environment for subsidence monitoring would include;

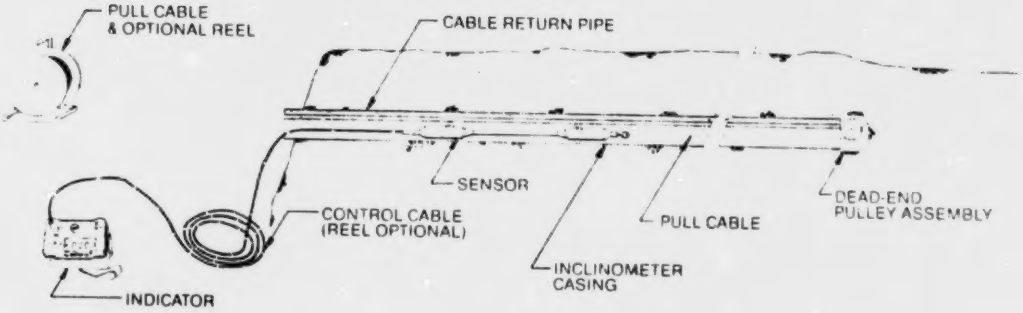
- materials of construction compatible with the salt water
- all joints sealed to pressure for the application (50 m of water)
- selection of pressure medium compatible with depth and temperature of operation;
- selection of suitable remote operations and readout mode

The level of accuracy indicated for each of the instruments is less than that indicated in the design criteria, which for vertical movements is specified as ± 1 mm, or a third order level of accuracy.

SETTLEMENT GAUGES :


System Schematic
Liquid column (sensing circuit)
Pneumatic control/readout circuit
Settlement Readout Instrument
Vent to atmosphere
Reservoir
Pneumatic supply
Regulator
Flow Controller
Gas flow
Supply pressure indicator
Sensor
Tubing Bundle

LIQUID TYPE


PULL CABLE & OPTIONAL REEL
CABLE RETURN PIPE
SENSOR
CONTROL CABLE (REEL OPTIONAL)
PULL CABLE
DEAD-END PULLEY ASSEMBLY
INCLINOMETER CASING
INDICATOR

INCLINOMETER TYPE

FIGURE 5-3

Solinst offer a system referred to as an "Automatic Settlement Plotter" which provides a continuous settlement profile to within ± 10 mm over distances of 1 km or more. It has the limitation, however, that the difference in elevation between the control panel and the tubing with which the settlements are monitored, cannot exceed 3.5 m. Its level of accuracy is also considerably less than that specified as being desirable.

Horizontal inclinometers, such as the Sinco model 50329 have also been used to monitor continuous settlement profiles beneath embankments and structures. This particular unit requires that a sensor be pulled through a casing. For seabed operation a method to pull the sensor between stations would need to be developed, or an in-place inclinometer system similar to the Sinco Series 504, which is designed for use in vertical boreholes, would need to be developed. The accuracy is stated as ± 2.5 mm per 30 m of casing which is within the level of accuracy specified.

A typical installation provides access to one or both ends of a casing for the purpose of moving the inclinometer along the casing and a readout station for manual readout. The manufacturer also offers a system that records readings on magnetic tape. Figure 5-3 shows one application. Remote operations within the marine environment would require adaptations.

Horizontal movements: Strain meters or extensometers have been used to monitor deformations in embankments and earth dams. A number of models are available;

Type	Model No.	Range
Sinco	51701	152 mm
Geonor	P-265	150 or 200 mm

The accuracy of these extensometers is well within that specified for subsidence monitoring; however, the range is not large and some modifications may need to be undertaken to allow measurements of the expected strains. The range of measurement is acceptable for the station spacing at the Prince Mine.

Tilt Measurements: Tiltmeters have been used as part of land based subsidence surveys, and several units are commercially available.

Type	Model No.	Range	Accuracy
Sinco	50322	± 30°	± 10 sec
Terrascience	---	± 6°	± 2 sec

The accuracy of each of the above units is well within the specified criteria. Other models are also available that have been used in subsidence monitoring. No modifiction is required for applications of these instruments within the marine enviornment.

General: Direct monitoring instrumentation is available and with minor marine adaptations and attention to output signal character could be applied to the proposed submarine subsidence monitoring program. Monitoring stations layout and inter-relationship has been identified and presented. A modification of the rosette and chain configurations has been recommended for use. Section 7 will discuss the specific marine applications in more detail.

6.1 INTRODUCTION

This section of the report will deal specifically with issues relating to the surveying and positioning aspects of the proposed offshore subsidence monitoring program as well as some indirect methods that may, with development, find applications for the proposed work.

Three basic approaches have been identified, reviewed and analyzed with a view of presenting the required information on the systems to the client so that proper decisions can be made concerning their usefulness and effectiveness for the above applications.

The different approaches identified include statements concerning the present accuracy of the systems and an indication of what development would be required which would lead "to the accurate determination and delineation of subsidence profiles at seafloor or seafloor-bedrock horizons".

6.2 PROJECT OVERVIEW

The statement of work required the evaluation of existing survey systems and procedures which can provide three dimensional (X, Y, Z) positional information for points on the seafloor.

The optimum accuracies for this work are in the order of ± 10 mm in all three components as outlined in Section 4 of this report. Systems which cannot attain this accuracy but which can give something better than ± 1m are reviewed because of two reasons:

- their potential as an optimum system with research and development support;
- the data which they can now supply may be of some use to the client.

The size of the area to be monitored will vary depending on the mine. Table 6-1 indicates the transverse and longitudinal dimensions of the limits of the area to be monitored for the three mines based on criteria stated in Section 5 of this report. This includes an area outside the area of subsidence required for the installation of a number of points on stable ground.

Table 6-1

Limits of Monitoring Area

Mine	Transverse	Longitudinal
No. 26	1200	1200
Lingan	1000	900
Prince	600	500

6.3 CAPE BRETON DEVELOPMENT CORPORATION UNDERGROUND SURVEY SYSTEM

An important aspect of this report is the investigation into the survey procedures utilized in the underground workings. Because the location of the points on the seabed will be determined from the coordinates of points on the perimeter of certain panels underground, it is necessary to have an indication of the positional accuracy of these underground points.

The survey procedures utilized by the Cape Breton Development Corporation are reviewed and the results of a pre-analysis computer program that was generated utilizing certain data pertaining to the Lingan Colliery are discussed.

Survey Procedures and Specifications

The survey procedures utilized for the measurement of angles and distances are as follows:

- angles are measured with a Wild T-16 (least count of 1 minute of arc, estimate to approximately 10 seconds of arc.) The angles are "doubled", that is there are two readings for each angle.
- the distances are taped or chained (least count of 0.03 metres). All distances are "check chained", that is there are two readings for each distance. Distances are reduced to the horizontal (corrected for slope) and corrected for sag.
- closed loops are run wherever possible as an internal check on the work and as a means of strengthening the network.
- when starting a traverse from points that were established previously, the stability of the starting points are confirmed by measuring between them. If these points are found to be unstable, other points are checked until stable ones are found (Phillips, 1984).

Coordinate Systems.

The Cape Breton Development Corporation has a local coordinate system on which all of the survey information is based. This system covers all of the mines under its jurisdiction.

This local system is integrated into the provincial coordinate system (LRIS) so coordinate information for underground points could be generated in the LRIS system if required. By the same token, any points established for the monitoring of mine subsidence could be based in the CBDC survey grid.The important point is that all information must be based on the same coordinate system.

Analysis of Survey Data

In order to get an indication of the quality of the positional data underground, CSC has performed a preanalysis of the network. This involved inputting the following information to a computer program.

- the standard deviation of the angular information (derived from the procedures utilized and outlined in the previous section)
- the standard deviation of the distance information (derived from the procedures utilized and outlined in the previous section)
- approximate coordinates for the traverse points. This was difficult to obtain from CBDC because of the tremendous amount of data and the fact that it is all in field book form. Based on discussions with their surveyors, certain assumptions were made concerning the location of these points.
- information concerning the connections between traverse points (closed loops, cross ties). Again certain assumptions had to be made.

An area was chosen in the Lingan Mine (Figure 6-1) and the above data was input into the computer program.

The main area of interest is the eastern portion of the 7E longwall because the positional accuracy would be degraded the worst in this area. The maximum error in position generated by the computer program was in the order of 4.5 metres. This may be considered a pessimistic value because all of the data which may affect the quality could not be utilized because of the limitations of the program. With all of the data being utilized and all of the cross ties and closed loops input into the program, we would expect a maximum positional error in the order of 3 metres.

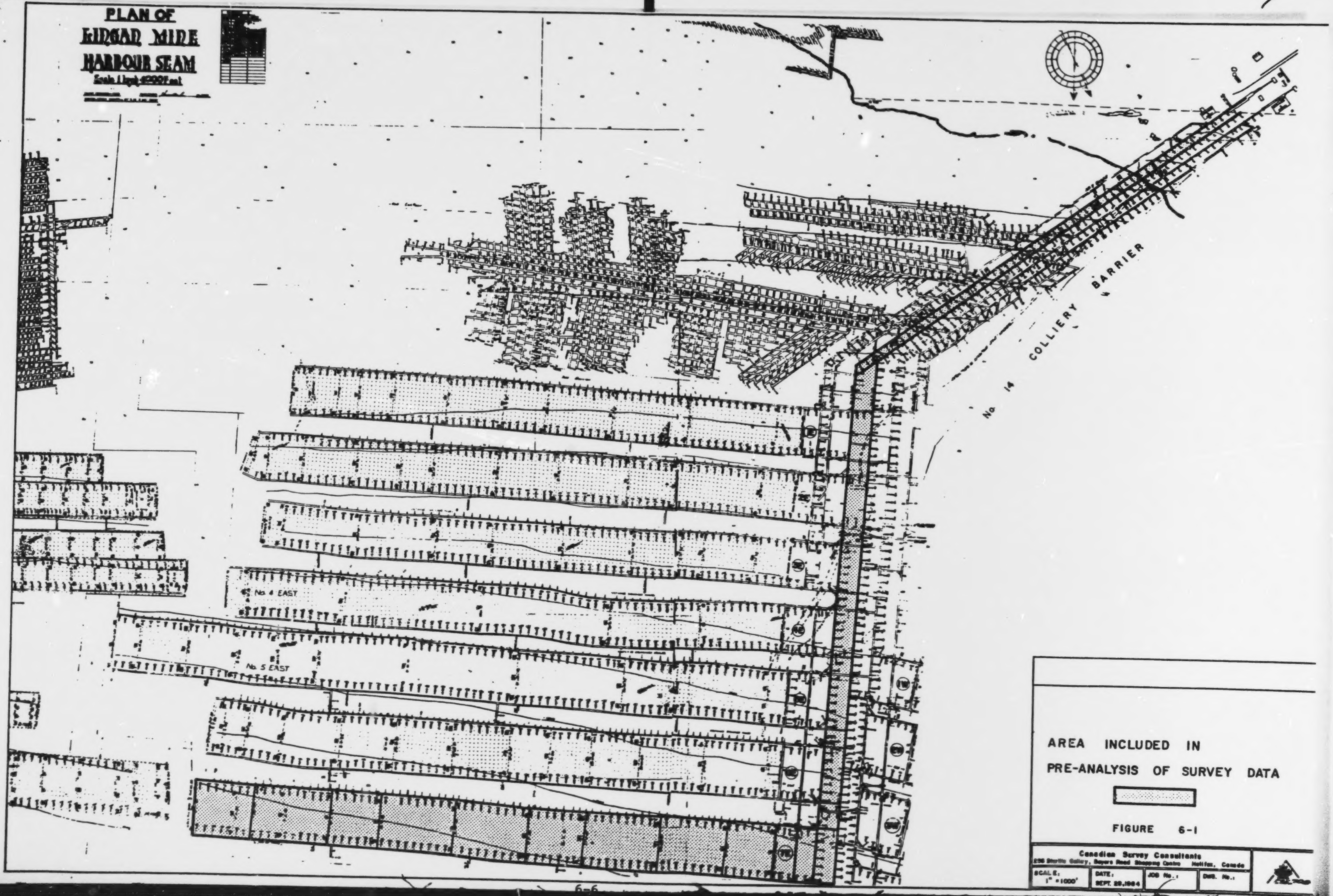
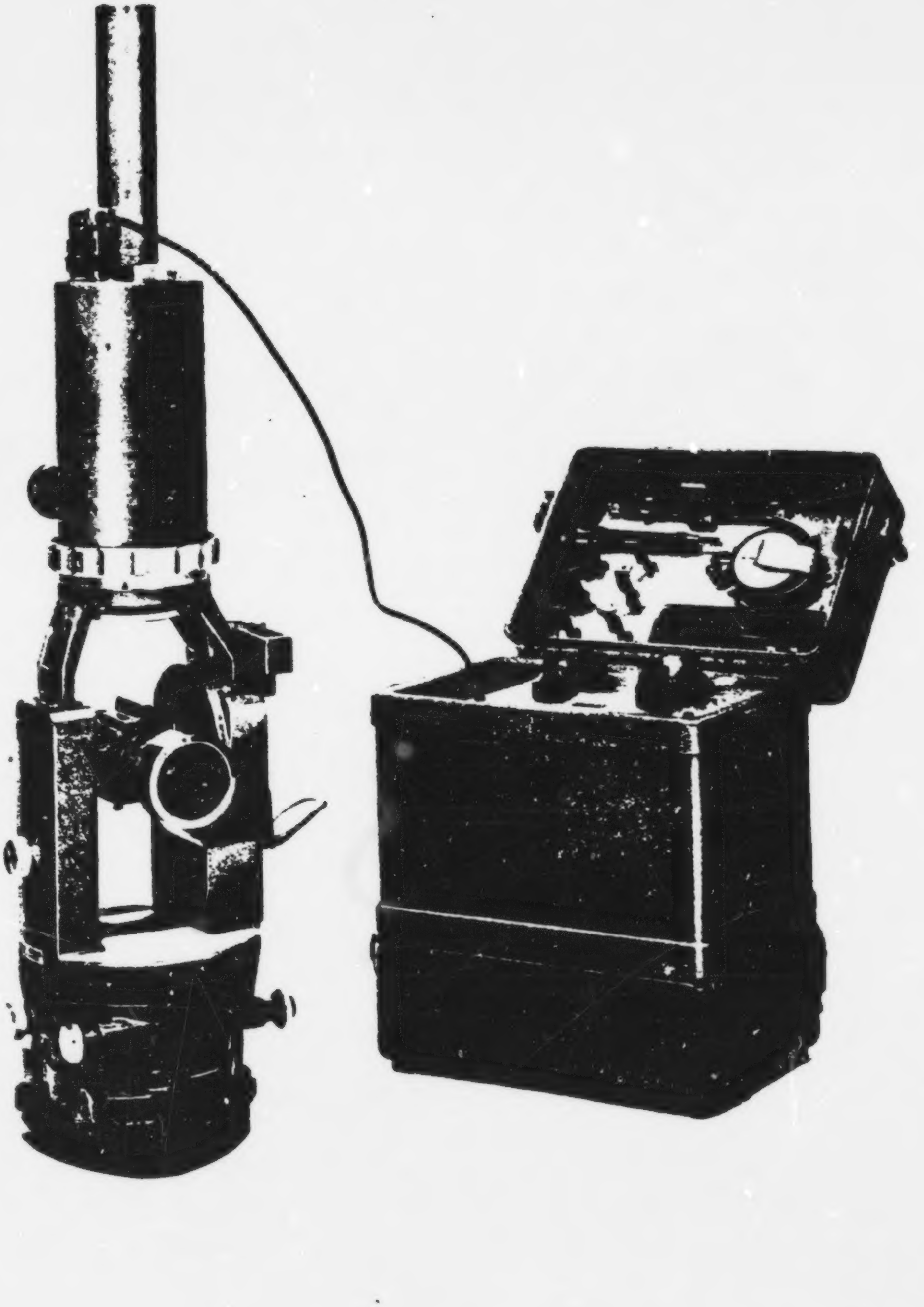

PLAN OF
LINGAN MINE
HARBOUR SEAM
No 14 COLLIERY BARRIER
No 4 EAST
No 5 EAST
AREA INCLUDED IN
PRE-ANALYSIS OF SURVEY DATA

FIGURE 6-1

Canadian Survey Consultants
238 Starlite Gallery, Bayers Road Shopping Centre Halifax, Canada
SCALE: 1" = 1000'
DATE: SEPT. 28, 1984
JOB No.:
DWG. No.:

In reviewing the survey information it was felt that azimuth control was the weak link in the underground network. Fictitious azimuth information at three points along the network was added and the pre-analysis program was run again. The results showed a significant reduction in the errors, the maximum of which was 1.5 metres.

If it is necessary to reduce the errors in the underground survey system, it is suggested that azimuth observations at three or four points using a gyroscope attachment to a theodolite be observed. Battery power is necessary to run this instrumentation which may require special permission to enter the mine with this equipment (Figure 6-2).



WILD GAKI GYROSCOPE ATTACHMENT

Figure 6-2

6.4 LAND BASED SUPPORT SYSTEMS FOR OFFSHORE SURVEYING

Description.

All offshore positioning systems must use, as a reference, a number of points of known positions or coordinates. For radio positioning systems there are usually two to four points on the coastline near to the working area. (Figure 6-3).

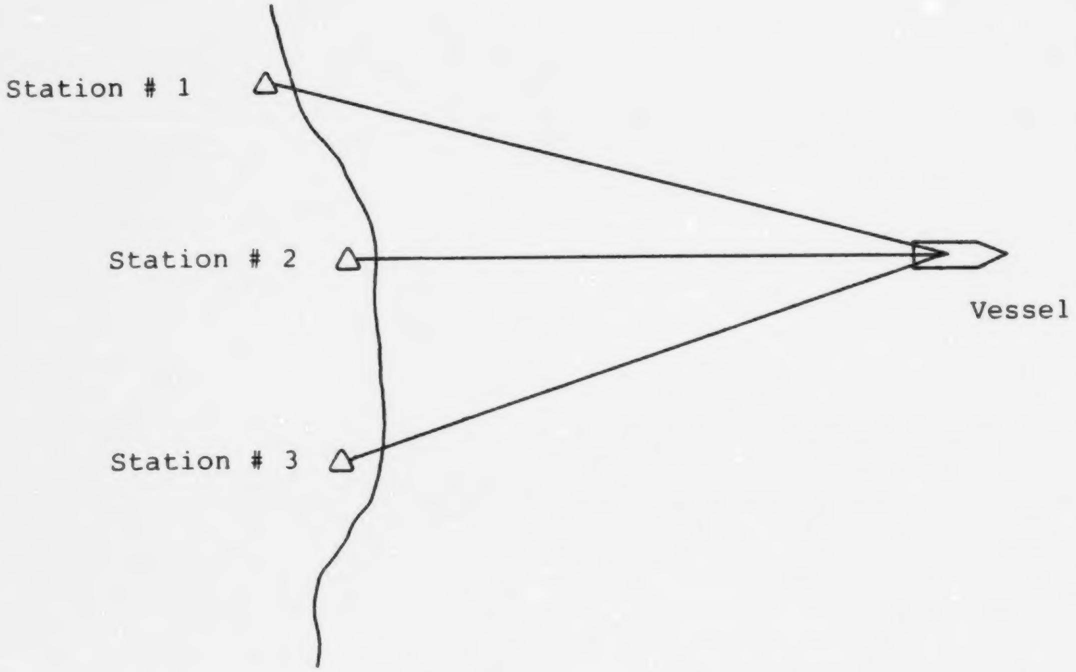
By knowing the coordinates of these points and measuring the ranges from each to the vessel, the position of the vessel in the same coordinate system as the shore control points can be derived.

There are two basic survey methods utilized for the derivation of the coordinates of the shore control points.

The first method involves traversing from two points of known coordinates to the shore points requiring coordinates. It involves the measurement of angles and distances for a series of traverse "legs" (Figure 6-4). From this information coordinates are calculated for the unknown shore points.

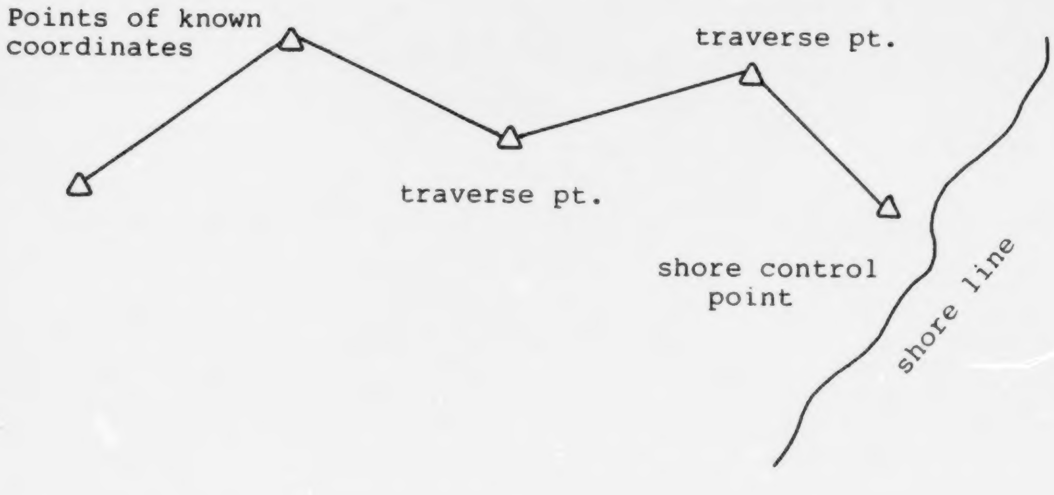
Angles are measured with an optical instrument such as a Kern electronic theodolite which has an instrumental error or 0.5 seconds of arc (Figure 6-5). Distances are measured with an electronic distance measuring device such as the Kern DM 502 which has a range of 1 to 2 km and an instrumental error of 3 mm + 5 ppm (Figure 6-6.) The Azimuth or orientation of the network is controlled by the known coordinates of the starting points. This may be augmented by azimuth observations of certain stars (including the sun) as a reference or by utilizing a gyroscope depending on the length of the traverse and the number of legs.

Instrumentation is now being developed which will perform all necessary data gathering functions with one unit and store the information on disc which can be readily processed by computer in the office. Accuracies of these instruments are similar to or better than those described above. (Figure 6-7).


Station # 1
Station # 2
Station # 3
Vessel

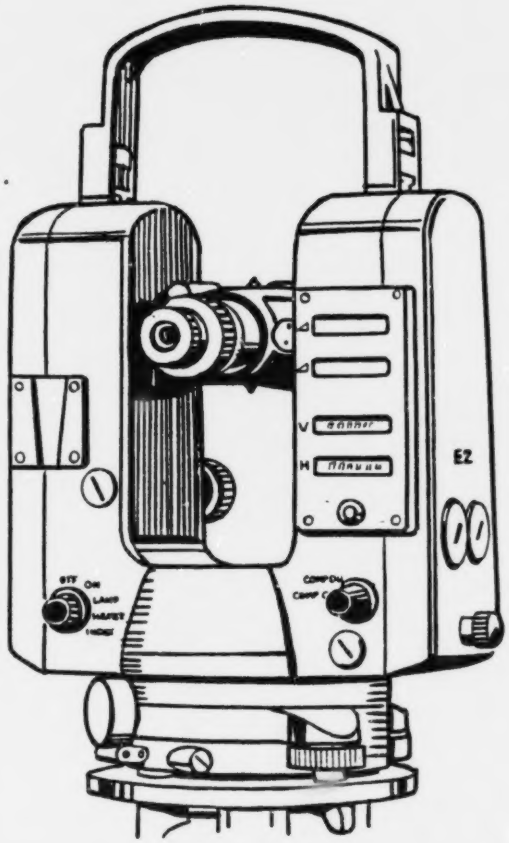
Shore Station Configuration

Figure 6-3


Points of known coordinates
traverse pt.
traverse pt.
shore control point
shore line

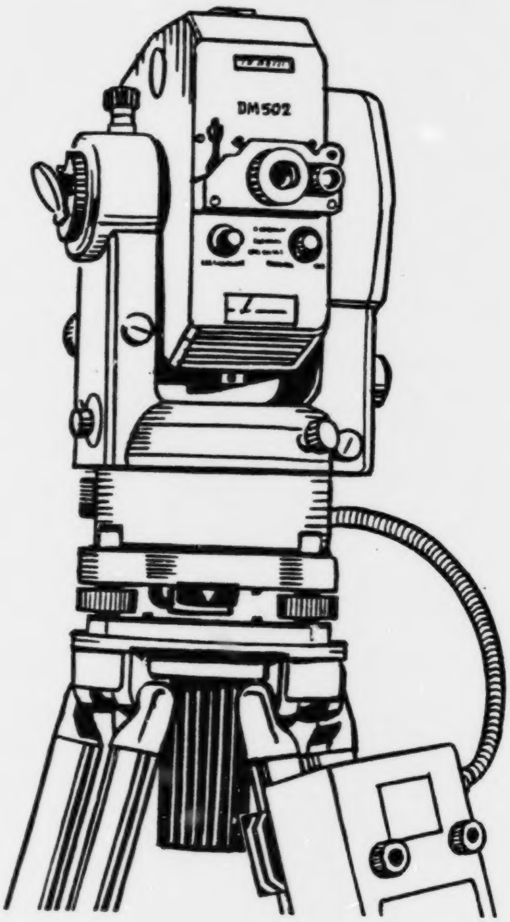
Example of a Survey Traverse

Figure 6-4


V
H
E2
OFF
ON
LAMP
COMP ON

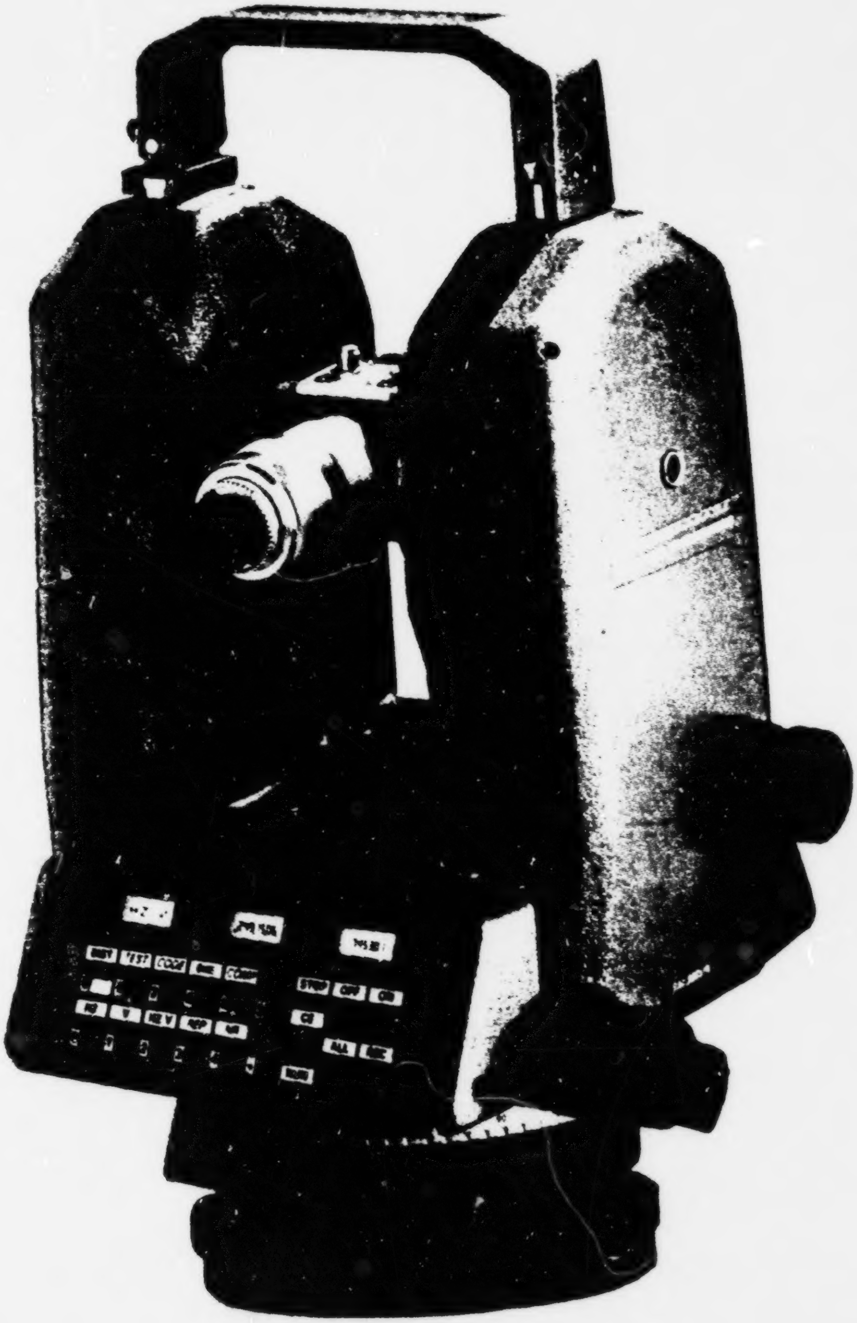
KERN ELECTRONIC THEODOLITE

Figure 6-5



KERN ELECTRO-OPTICAL DISTANCE METER

Figure 6-6



AUTOMATIC DATA GATHERING DEVICE

Figure 6-7

The other method used to establish coordinates of unknown points is the utilization of the Doppler Satellite technique. Two satellite receivers are used in the field, one placed over a point of known coordinates and one placed over the point being established. As a satellite passes over the area, data is received at both stations from which coordinates are calculated for the unknown point. (Figure 6-8).

The receivers must be left in the field for 1 to 3 days in order to acquire enough information to accurately position the unknown point. (Figure 6-9).

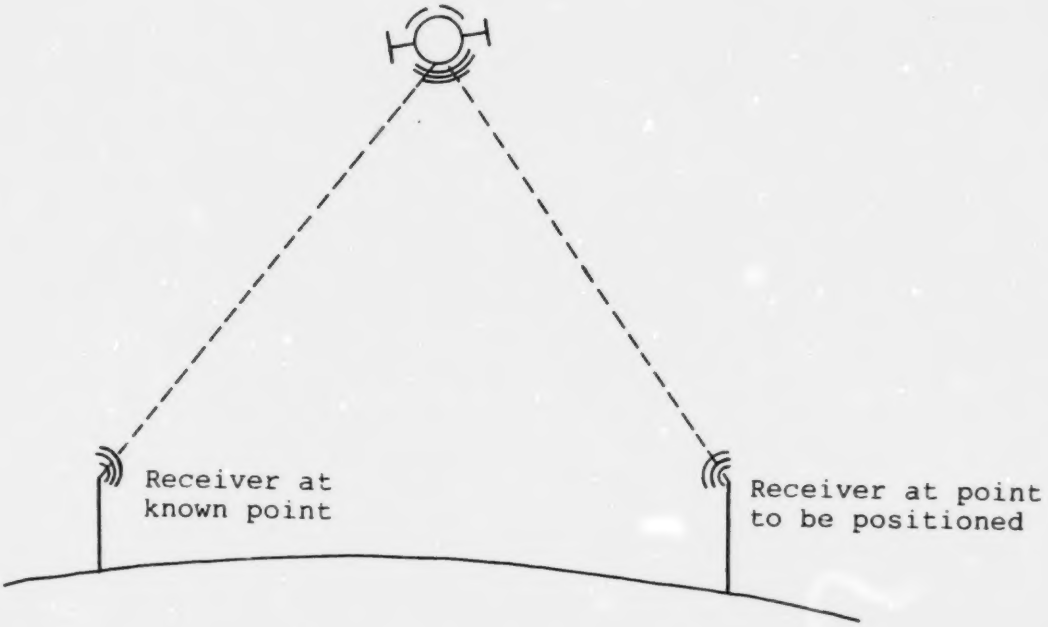
Both methods can be utilized effectively for the surveying of shore stations required for offshore positioning. The method chosen would be based on distance from existing control monuments, terrain conditions and final accuracy required. For this project, existing control monuments are readily accessible and within a short distance (1-10 km) of any potential shore station locations. The conventional traversing technique would probably be used to provide coordinates with positional accuracy of less than 1m.

Application and Analysis

The above systems require the instrumentation to remain in one place and stationary over a length of time ranging from fifteen minutes to three days. Because of this its application is limited in the offshore environment.

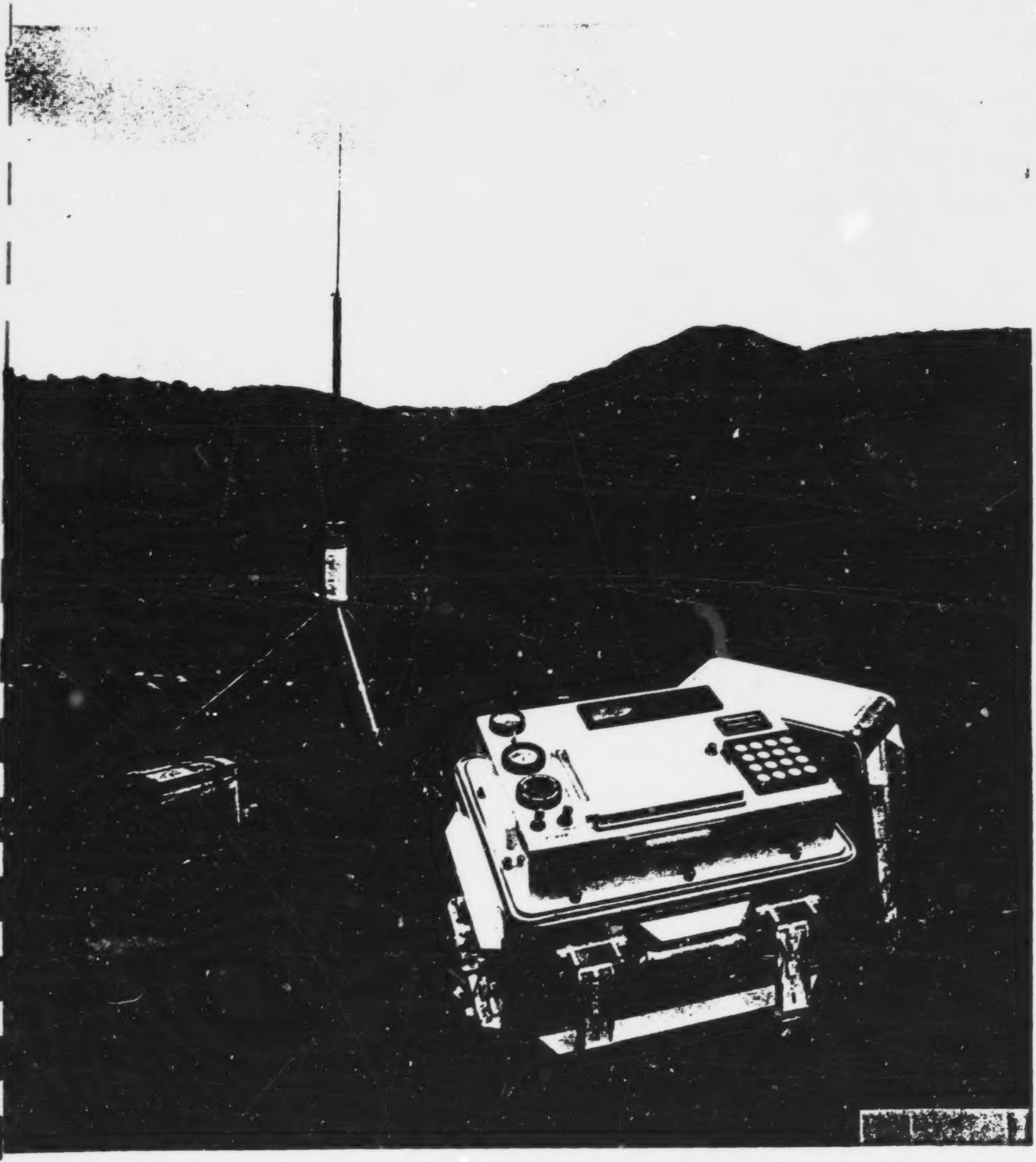
The main application would be in the area of establishing control on land needed for the offshore survey system and in integrating this control with the underground survey system.

The use of these systems to measure subsidence would be feasible only if a water-free environment was established over the working area as described in Section 4 of this report.


Receiver at
known point
Receiver at point
to be positioned

Survey Using Satellite Data

Figure 6 - 8



MAGNAVOX SATELLITE RECEIVER

Figure 6-9

6.5 POTENTIAL MEASURING SYSTEMS

Different measuring systems that could be utilized in the monitoring of mine subsidence are discussed. A description of the systems is given and an analysis based on our knowledge of the requirements for monitoring subsidence on the seabed. The conventional land based systems for measuring actual subsidence are contained in Section 4.

Sea Surface Systems

There are numerous navigation systems available which will position a vessel on the surface of the ocean. In combination with a sounding system which records the depth of the sea bottom, three-dimensional (X,Y,Z) values can be determined for certain points on the sea floor.

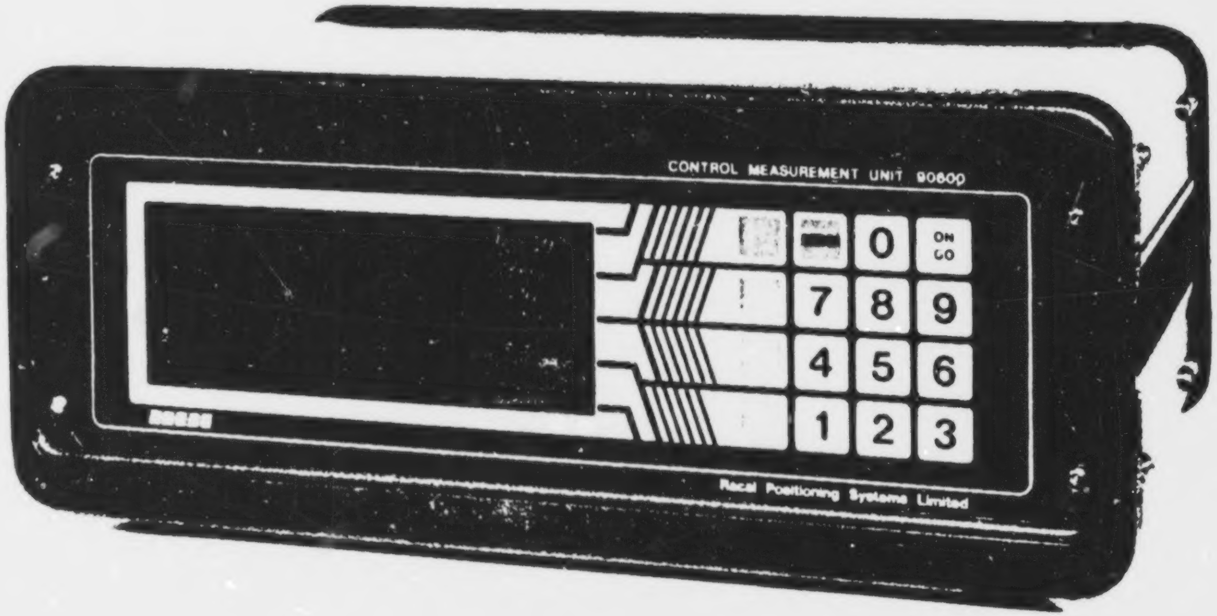
Description

Radio Positioning Systems

The position of the vessel is determined using high frequency radio positioning systems. These systems consist of receivers on shore stations of known coordinates and a mobile station on the vessel itself. Signals of a known frequency are sent out from the vessel to the shore stations where they are returned to the vessel. The time is measured and the distance from the vessel to each of the shore stations is derived. Figure 6-10 is an example of the hardware involved in a radio positioning system. This information is then fed into a navigation software program where the position (X, Y) of the vessel is determined.

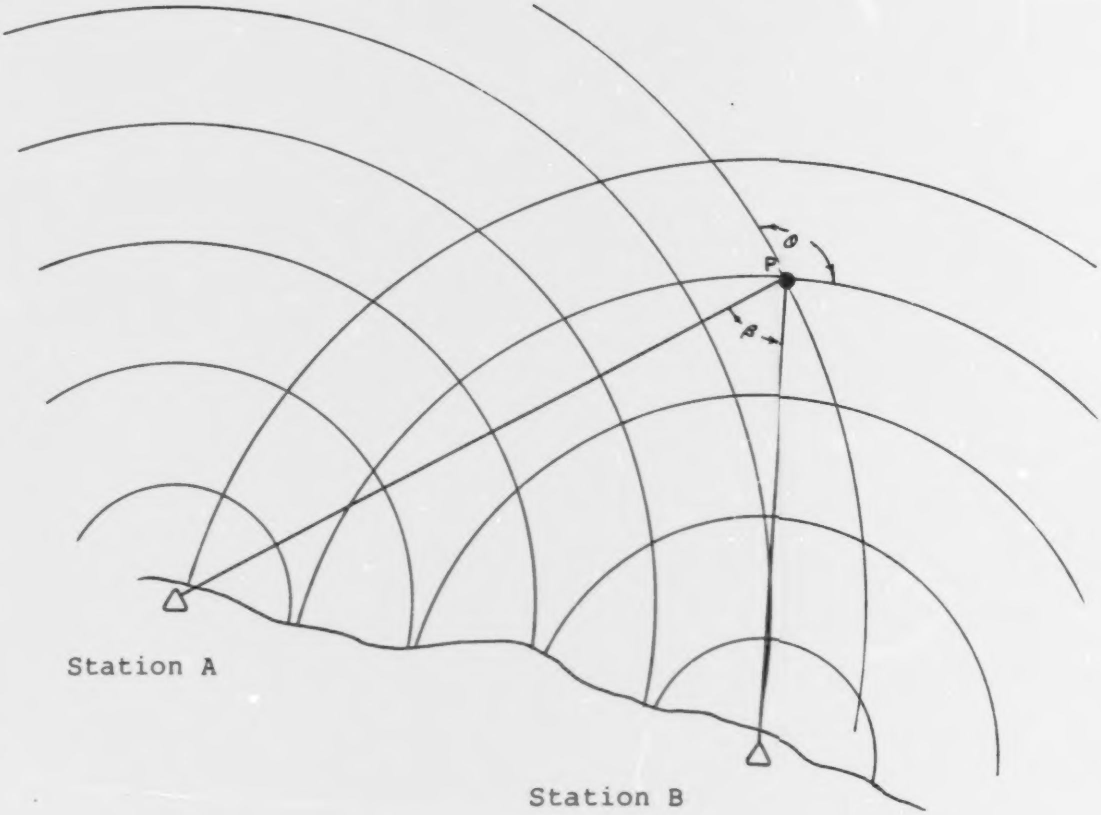
The positioning accuracy of any radio positioning system depends on two factors:

- the accuracy of an individual measurement which depends on instrumental accuracy, knowledge of the propagation velocity and care taken in calibration.
- the fix geometry factor, or geometric dilution of position (GDOP),or the ratio of the position error to the measurement error. It depends on the angle at which the lines of position intersect. (Figure 6-11).


CONTROL MEASUREMENT UNIT 90600
ON GO
0
7
8
9
4
5
6
1
2
3
Racal Positioning Systems Limited

RADIO POSITIONING SYSTEM

Figure 6-10


P
θ
β
Station A
Station B

Intersecting Position Lines

Figure 6-11

Using this configuration the intersection angle is given by $\theta = 180° - B$ where B is the angle between the range lines at P

The equation for the error in position at point P is:

$$\text{drms} = \operatorname{cosec}\theta \sqrt{\sigma_A{}^2 + \sigma_B{}^2 - K_{AB}\,\sigma_A\,\sigma_B\cos\beta}$$

where σ_A and σ_B are the standard deviations of the range measurements from the two shore stations

K_{AB} is a correlation coefficient between the measurements from the two stations.

The best positional accuracy then occurs where there is high correlation and K_{AB} approaches 1 and the angle of intersection at P is equal to 90° .

In radio positioning systems, the higher the frequency the more accurate the measurements. This is because it is very difficult to measure more accurately than about 1/100 of a wavelength and it is difficult to estimate the propagation velocity over longer ranges. Also, the range of the systems decrease with higher velocity.

For the purpose of this report, the most accurate system available is required. This would then be the microwave or super high frequency systems. They are restricted in range to "line of sight" which is typically 30 Km and are capable of operating in adverse weather conditions such as fog, rain and snow.

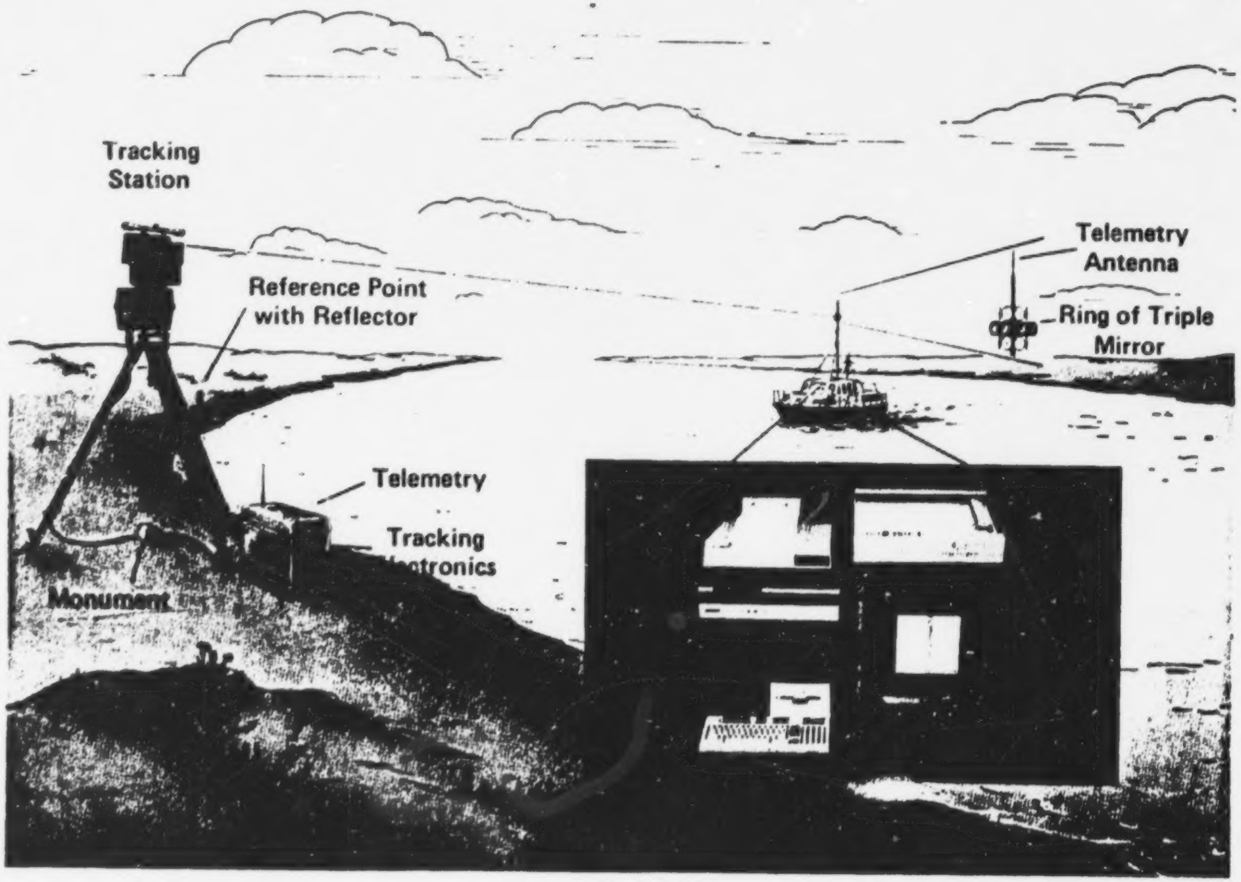
Table 6-2 shows the different high frequency systems available and their corresponding accuracies.

A different concept for short range dynamic positioning systems is now being developed which offers an alternative to the range intersection approach. The system uses a range/azimuth fixing technique to position a moving vessel. The vessel is "tracked" by a laser beam emitted from a shore station. The system is microprocessor controlled with data being transferred by telemetry from the shore to the vessel where it is processed (Figure 6-12).

TABLE 6-2

INSHORE - SHORT RANGE SYSTEMS

System	Principle	Mode	No of Users	Operating Frequency	Resolution	Measurement Accuracy	Max. Range	Special Characteristics.
Artemis	Mutually tracking antennae microwave ranging	Range/ Bearing	single	9 GHZ	0.1 m B mode 1 m A mode	1.5 m 2' arc	15 km 30 km LOS	Only one shore station required.
Autotape	Phase comparison	Range/range	single	3 GHZ	0.1 m	0.5 m ± 10-6 range	150 km LOS	Two-way voice communication sequential range measurement on 3 channel
Miniran	Precision Microwave Ranging	Ranging	6 normal 22 theory	3 GHZ	1 m	2 m	45 km LOS	Simultaneous interrogations and replies possible.
Miniranger III	Pulse Measurement	Range/Range (Rho-theta optional)	10 time sharing	5 or 9 GHZ	1 m	3 m	37 km 105 km Optional	Manufacturer can tailor a system to users needs (over 100 options).
Syledis	Pulse Measurement	HYP Range/Range/ HYP	unlimited 4-R_R	420 MHZ	0.1 m	1 m	120 km LOS	Low maintenance requirements.
Telluro-meter	Phase comparison	Range/Range	single, 3 with time sharing	3 GHZ	0.1 m	1.5 m 0.5 ± 3x10-6	250 km LOS	Two-way voice communication
Trident III	Pulse Measurement	Ranging	50 max 4 simultaneous Interrogations	400 MHZ 600 MHZ or 1300 MHZ	1 m	3 m	250 km LOS	Simultaneous coded pulse are sent to 2, 3 or 4 shore stations.
Trisponder	Pulse Measurement	Ranging	4 with time sharing	9 GHZ	0.5 m	3 m	80 km LOS	Multi-tracker configuration capable of tracking 30 moving targets.
Micro-fix	Pulse Measurement	Ranging	16	5 GHZ	0.1 m	1 m	80 km LOS	Automatic and continuous self calibration.
Polar-fix	Laser beam tracking	Range/Range	Single			0.1m ± 0.1m/km 0.01°	5 km	Data from shore station telemetered to survey vessel for processing.


Tracking Station
Reference Point with Reflector
Telemetry
Tracking Electronics
Monument
Telemetry Antenna
Ring of Triple Mirror

RANGE/BEARING SYSTEM

Figure 6-12

Because the system uses a range/bearing concept, the geometry limitation of the range intersection technique is eliminated. The maximum range of this system presently is 5 km. At this range the accuracy of the system is ± 1.04 m. Longer ranges are being tested at this time by the manufacturer. The horizontal distance from shore for the Lingan, Prince and No. 26 mines are 3.4, 2.4 and 6.5 Km respectively. This system could then be utilized for work in the Lingan and Prince area. The range of the No. 26 is too far for the system in its present state of development. Information on these systems is also includes in Table 6-2.

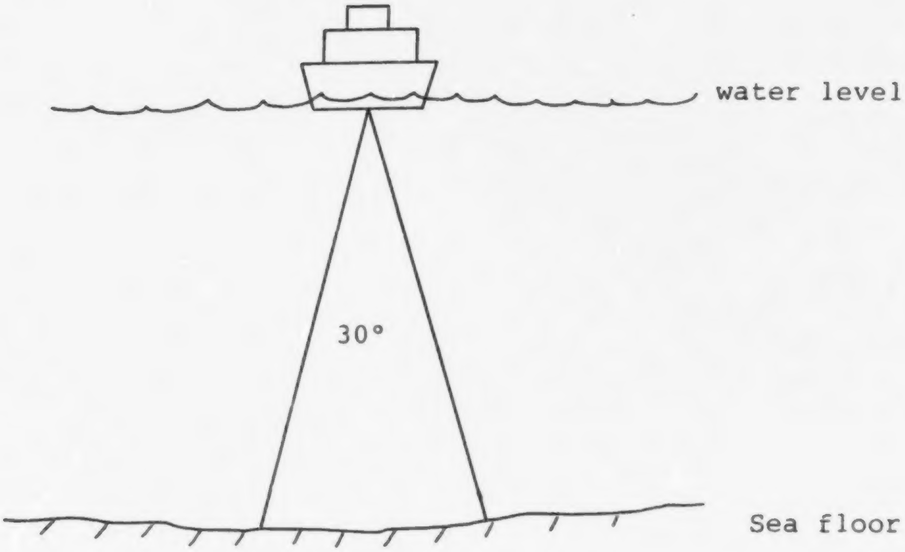
Depth Measurement System.

The other component in determining the position (X, Y, Z values) of points on the sea bed is the depth.

The main component of this system is the echosounder. The echosounder works on the same principle as the radio positioning system except the medium in which it is functioning is water and a pulse is reflected off the sea bed instead of another instrument. The echosounder measures the time that it takes for a pulse of sound to travel from the transmitter to the sea bed and back again. It then calculates the depth by mutliplying by the velocity of sound in water.

The echosounder transmits a pulse through a transducer. The pulse varies in frequency duration and shape depending on the transducer. High frequency pulses have compact transducers but their range is limited. Transducers are designed to concentrate the beam width. It is usually considered to be a cone with a vertex angle of 30°. (Figure 6-13).

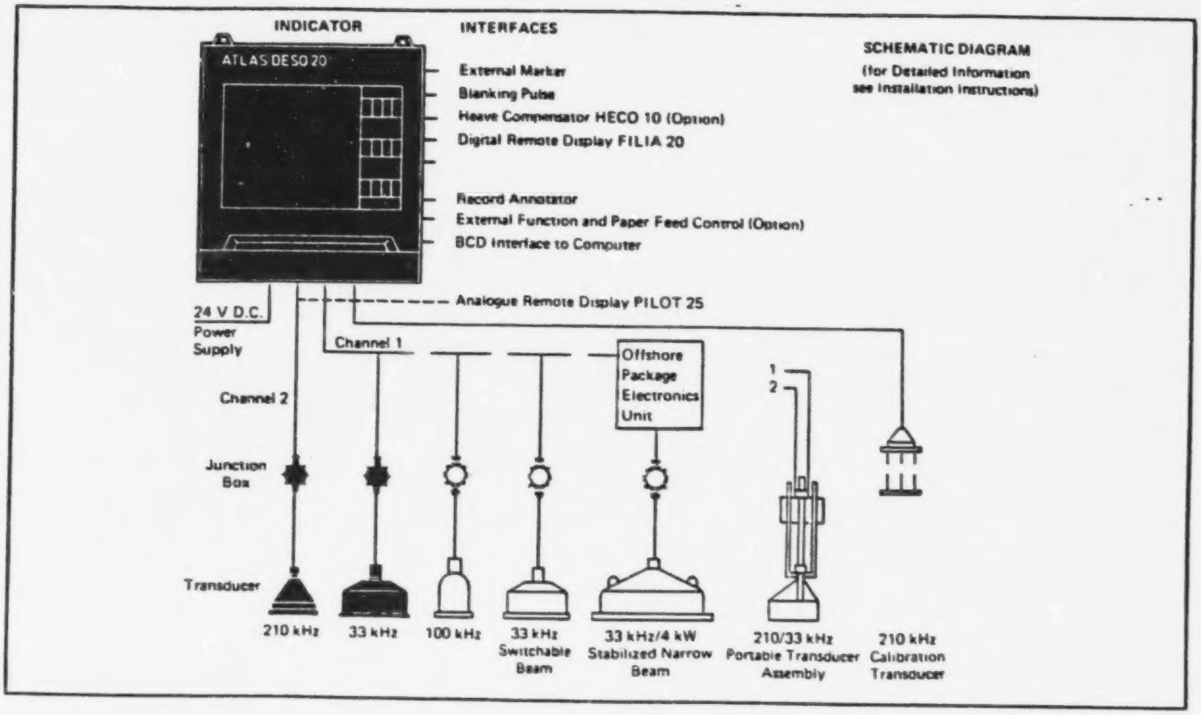
The dual-channel echosounder Krupp Atlas Deso 20 (Figure 6-14), one of the more accurate survey sounders can be used for surveying rivers, harbours, coastal strips and offshore areas, even in extreme conditions. The compact system as a combined analogue/digital survey echosounder


water level
30°
Sea floor

BEAM WIDTH CONFIGURATION

Figure 6-13

Atlas Deso 20


INDICATOR
INTERFACES
SCHEMATIC DIAGRAM
(for Detailed Information see Installation Instructions)
ATLAS DESO 20
External Marker
Blanking Pulse
Heave Compensator HECO 10 (Option)
Digital Remote Display FILIA 20
Record Annotator
External Function and Paper Feed Control (Option)
BCD Interface to Computer
Analogue Remote Display PILOT 25
24 V D.C. Power Supply
Channel 1
Channel 2
Offshore Package Electronics Unit
1
2
Junction Box
Transducer
210 kHz
33 kHz
100 kHz
33 kHz Switchable Beam
33 kHz/4 kW Stabilized Narrow Beam
210/33 kHz Portable Transducer Assembly
210 kHz Calibration Transducer

ECHOSOUNDING SYSTEM

Figure 6-14

has been technically designed in such a way that a whole range of applications can be catered to by various extended versions. The Deso 20 can be used in hydrographic surveying either as an individual unit or as part of an automatic survey system.

Operating with two different frequencies simultaneously the Deso 20 provides a differentiated display of bottom layers of varying thickness, organic silts in navigation channels, and also for detecting wrecks, pipelines and cables. Use is made of the special reflection characteristics of bodies at differing frequencies. While echosounding pulses of higher frequency are fully reflected at a silt surface, pulses of lower frequency penetrate the bottom and produce echos at the various sedimentary layers. The standard combination of 33 Khz and 210 Khz for echosounding frequencies has proven itself in practice.

The Atlas Deso 20 uses ultrasonic waves for measuring water depth. A short burst of ultrasound is emitted vertically downwards to the water by a transducer, which converts electrical energy into mechanical energy. Part of the sound energy is reflected by the bottom or other solid media, and returns to the transducer as an echo. The time between the transmission of the ultrasonic signal and the return of its echo is a measure of the depth. The accuracy of the depth measurement depends on accurate knowledge of the speed of sound in water. This is measured with the calibration transducer and input to the Deso digitally. In addition, the draught of the vessel and the depth threshold (depth gating feature) are entered and the echograph and digital readout are adjusted to this. The Deso 20 is capable of 55 different measuring range combinations, the beginning and end of which are shown in numerals in the righthand display field.

There are a number of error sources involved in depth measurements using a sounder. These include location of reflection, wave motion, velocity propagation, tides and water levels.

Location of Reflection.

The first returns of the pulse comes from the

closest reflector and not necessarily from the bottom directly underneath the vessel. This will cause an error in depth over a non-uniform bottom (Figure 6-15).
Because of the high accuracy requirement of this project a narrow beam transducer is recommended.

Wave Motion.

Wave motion as it affects the survey vessel is monitored using a heave compensator such as the Heco 10 Heave Meter (Figure 6-16). This instrument measures the vertical movements of the vessel and corrects the graphical and digital displays on an echosounder. The heave-meter instrument is made up of a heave sensor, vibration insulator, amplifier unit, converter, starter box and control unit. The system operates by an inertial method as follows:

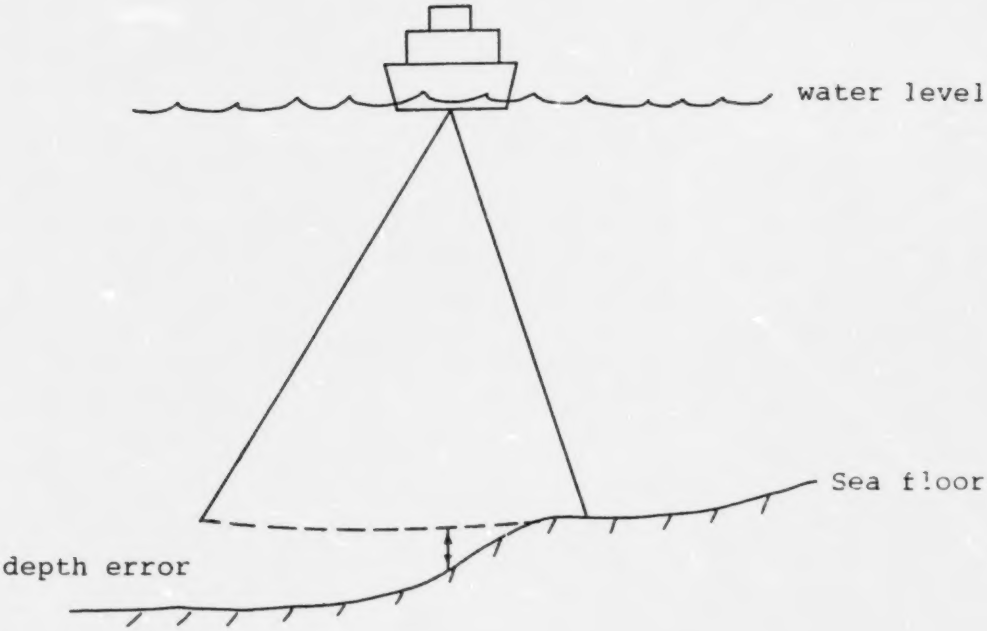
An accelerometer with its sensitive axis vertically stabilized by a liquid erected vertical gyro, measures the vertical accelerations resulting from rough seas. The acceleration meter signal is fed into an analog amplifier which is in the range of wave periods from 1s to 20s. Thus, by double intergration of the heave acceleration, the heave itself will be calculated. By means of further linear amplification the signal will reach an analog level of low resistance with a sensitivity of 4 V/m being available at the output of the heave-meter instrument (control unit). This permits the direct connection to the compensation inputs of echo sounders such as the Atlas Deso 20.

Velocity of Progagation.

The determination of the velocity of sound in water is very important and a major factor in increasing the accuracy of the vertical component of the positional information. In theory, the depth is determined by knowing the velocity at every point along the water column and integrating over the distance using the formula:

$$d = \frac{1}{2} \int_{t_t}^{t_r} c(t)\, dt$$

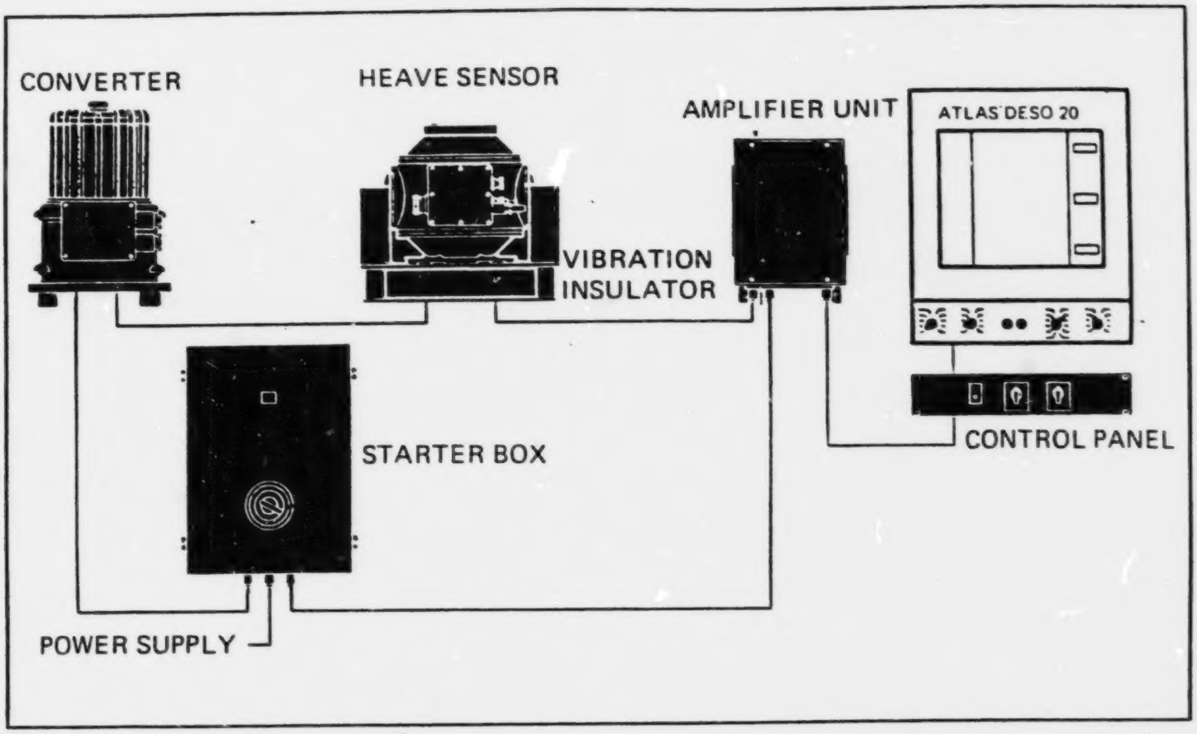
where t_t and t_r are the instants of time transmissions and echo reception respectively, $c\ (t)$ is the velocity at point t and d is the depth.


water level
Sea floor
depth error

ERROR CAUSED by LOCATION of REFLECTION

Figure 6-15

Atlas Heco 10


CONVERTER
HEAVE SENSOR
AMPLIFIER UNIT
ATLAS DESO 20
VIBRATION INSULATOR
STARTER BOX
CONTROL PANEL
POWER SUPPLY

HEAVE COMPENSATION SYSTEM

Figure 6-16

In practice, a mean velocity is determined along the water column and this is input into the formula:

$$d = \frac{1}{2} \; Cm \; . \; \Delta t$$

where Cm is the mean velocity, Δt is the difference in time between transmission and reception and d is the depth.

The mean velocity can be determined by three different methods including (i) a bar check; (ii) direct measurement of sound velocity using a velocimeter; (iii) measurement of temperature, salinity and pressure along the water column for the computation of velocity using tables and formulae.

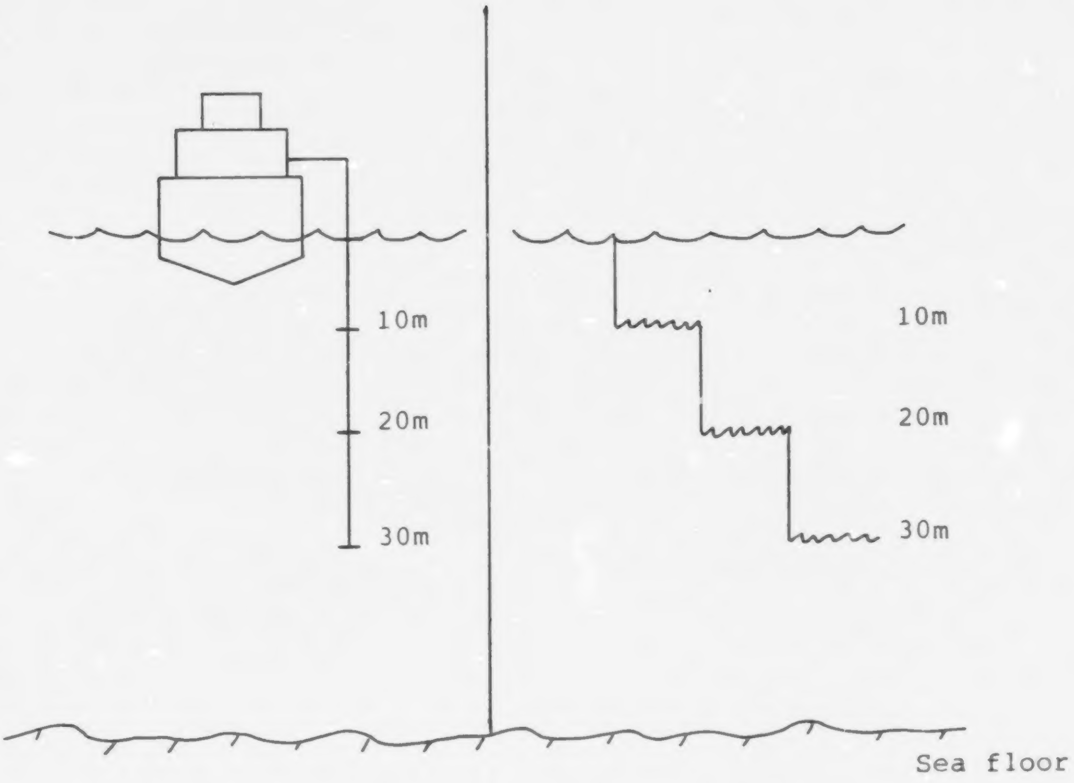
A bar check involves lowering a metal bar in the water to known depths and recording the sounding depth. The sound velocity can be calculated for any part of the water column and used either in the post processing of the data or to properly set up and adjust the sounder (Figure 6-17).

Another method is to utilize a velocimeter. This is an acoustic device that measures the travel time of short acoustic pulses along a fixed path of known length between a projector and receiver. The period for one cycle or the pulse repetition rate is measured on a frequency counter. The repetition frequency of the pulse is directly a function of the sound velocity. By obtaining the velocity of several known depths along a water column, the mean sound velocity can be calculated.

The third method is to determine the velocity as a function of temperature, pressure and salinity. Data can be obtained in the project area using standard probes and sensors and applied to the following equation:

$$C = 1449.2 + 4.6t - 0.055t^2 + 0.00029t^3 + (1.34-0.010t)(S-35) + 0.016d$$

where d is the depth (determined by the pressure), t is the temperature, S is the salinity and C is the propagation velocity.


10m
20m
30m
10m
20m
30m
Sea floor

Sounder Bar Check for calibration

Figure 6-17

The basic effects of salinity, temperature and pressure on the propagation velocity is noted in Table 6-3 (Thompson, et at., 1978).

Table 6-4 shows the error in range as a result of errors in the velocity at a depth of 20 metres which is the water depth over the Lingan and No. 26 workings.

A more detailed formula is available which will determine the velocity with a standard deviation of .3 m/s. The error effect of depth on velocity is also shown in Table 6-4.

Water Level Measurement.

Another factor which must be taken into account is water levels, which is affected by tides and sea state. The water level changes must be measured at all times during a survey of this type so that data can be accurately related to the appropriate datum.

Water level sensors are used to measure these constant changes in tides. The data is automatically recorded in either analog or digital format that can be stored for use in post processing or transmitted directly to the positioning system for immediate application. Tide gauges are placed in some protected box or area where any unwanted action such as wind and waves are dampened out. It is recommended that offshore tide gauges which are bottom mounted be utilized. Two gauges would be installed outside the subsidence area. Tidal information would be continually recorded and retrieved on some regular basis or telemetered to shore for input into the computations. Sea ice during the winter months could damage these tide gauges so it would be necessary to know the exact extent and magnitude of sea ice in the area.

As stated above, tidal information can be gathered continuously from instrumentation deployed in the area and then telemetered to shore or a survey vessel for processing.

In a sea surface system, telemetry could be utilized in the transfer of tidal records and sea condition information (temperature, salinity) from the recording units to the survey vessel. This data would then be integrated in the position solution (X, Y, Z) for the various instrument points.

Table 6-3

Factors Affecting Velocity of Sound

	Typical Values	Effect	Direction of Effect
Salinity	34 to 35 °/oo	1.3 m/s per °/oo	Increases
Temperature	0 to 10°C	4.5 m/s per 1°C	Increases
Pressure	0 to 200 m	1.5 m/s per 100m	Increases

Table 6-4

Error in Depth caused by Uncertainty in Velocity Propagation

Error in Velocity.	Error in Depth.
5 m/s	7 cm
1 m/s	1 cm
.3 m/s	0.4 cm

A telemetry system includes a bottom unit which is placed on the seafloor and a receiver unit which is placed on the survey vessel. (Figure 6-18).

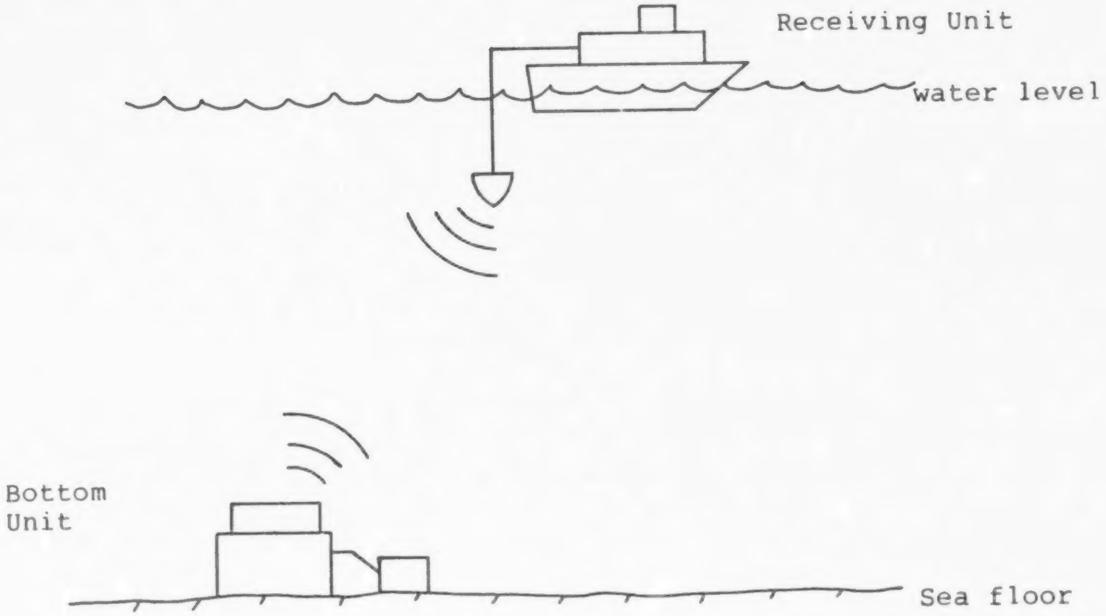
The bottom unit is connected to a tide gauge via an interface and moored to the ocean floor. The data is collected and stored in a microcomputer memory housed in the unit. The bottom unit is interrogated by the receiving unit on board the survey vessel at a frequency of around 8000 HZ. When communication is established and verified, the tidal information is transmitted from the bottom unit to the receiving unit where processing begins. (Morgera, 1983).

For this project, it would be advisable to establish two bottom units in the project area so that accurate and reliable tidal information could be acquired.

Another method utilized to monitor vertical fluctuations in water level is "benchmark" detection. The benchmarks are 3 m by 3 m steel plates welded to a base formed by 45 gallon steel drums. Two of these benchmarks are deployed on flat areas of the sea bottom within a kilometre of the project area. Once they are in place the survey vessel runs a number of sounding lines over the structures. Because of the high reflectivity of the benchmarks they show up on a sounding trace as a very distinctive feature. After numerous runs over them a mean position is calculated and a mean water level is established. Before and after each survey the benchmarks are found and a water level correction factor applied.

In this manner every survey can be related to all other surveys done in a particular area. This method also provides an excellent horizontal position check.

Table 6-5 depicts the expected accuracy at the water depths over the different coal mines taking into account all of the factors and errors discussed.


Receiving Unit
water level
Bottom
Unit
Sea floor

Telemetry System

Figure 6-18

Table 6-5

Sounding Accuracy

Coal Mine	Water Depth (metres)	Sounding Accuracy (metres)
Prince	9.1	0.076 m
Lingan	31.1	0.102 m
No. 26	31.1	0.102 m
Donkin	18.3	0.087 m

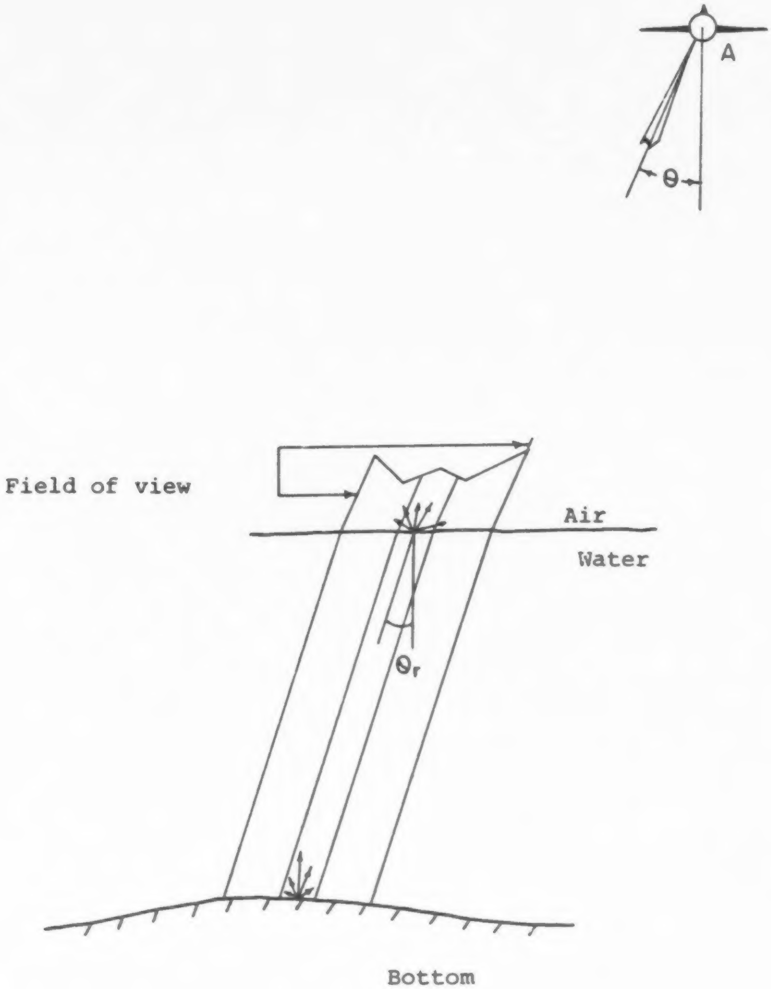
Laser Bathymetry.

In recent years, laser bathymetry has been developed and will continue to be developed to a point where it will be useful in the collection of bathymetric data.

The principle of the system is that a lidar (light detection and ranging) device uses electromagnetic radiation in the optical spectrum to sense the position of remote objects such as the sea bottom. It supplies its own source of illumination which is the laser. The theory is the same as an acoustic sounder where the time difference is measured from the transmission of the signal until its return. The system has been developed for use in an aircraft or helicopter. The system concept is depicted in Figure 6-19. A laser on board the aircraft at A fires a pulse of light towards the water at angle 0. At the water surface, a portion of the pulse is reflected back to the aircraft and the remainder refracts into the water. The refracted pulse undergoes scattering and absorption and eventually a portion of this pulse reaches the bottom and is scattered upwards. The receiver at A then receives the surface reflection pulse and at some later time, the bottom reflected pulse. The difference in time can then be used to compute the water depth.

Because the laser is an optical beam, scattering of the return beam causes errors in the depth determining process. By knowing certain water quality parameters, these errors can be minimized. The water quality parameters can be estimated directly from the wave form shape (Anderson, et al, 1983).

Laser bathymetry is the latest technological development concerning depth determination systems. It is still in the development stage but is proceeding in the United States, Canada, Australia and Sweden. It's development is occurring because of the attractive prospects of offering a system which has the advantages of speed and mobility over a vessel mounted echosounder.


A
θ
Field of view
Air
Water
θr
Bottom

LASER BATHYMETRY

Figure 6-19

Target/Grid Point Design.

In order to determine the X, Y, Z values for the measurement points, stations must be placed on the seabed which will return a definite and clear echo to the sounding graph. This will provide the most accurate location and depth information for each of the points.

Because of the high horizontal accuracy requirements, targets should be designed to optimize the horizontal location of the centre point. An example of this would be to utilize a cross shaped target made from a solid metal material such as steel rail (Figure 6-20) of dimensions 1m to 2m leg length.

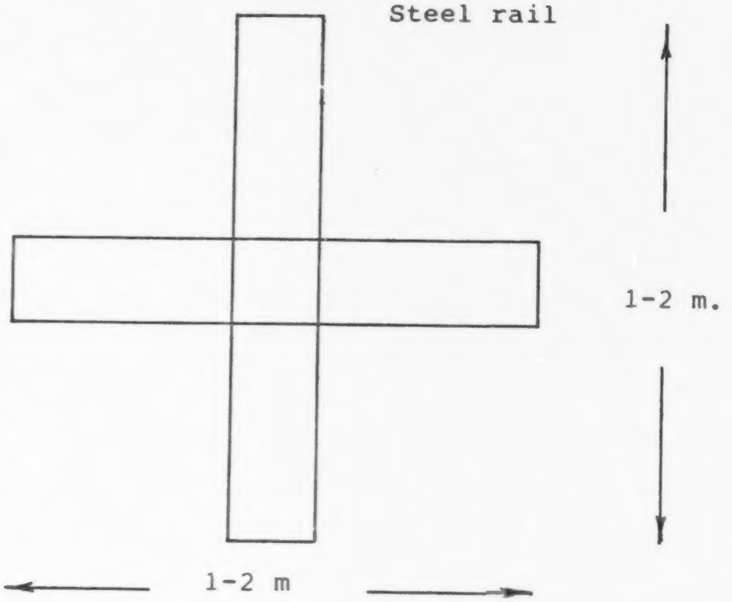
This target would be placed over each measurement point and levelled as accurately as possible. It would also be oriented as closely as possible to the transverse and longitudinal directions of the panels and elevated above the seafloor.

A number of runs would be taken over the target to establish positions for each bar on the sounding graph (Figure 6-21). Using the X,Y information for each point and an intersection technique, an accurate X, Y position of the centre point can be determined. Using this information and the gradient information derived from the measured values, an accurate depth can also be computed for the centre point.

Taut Wire Application.

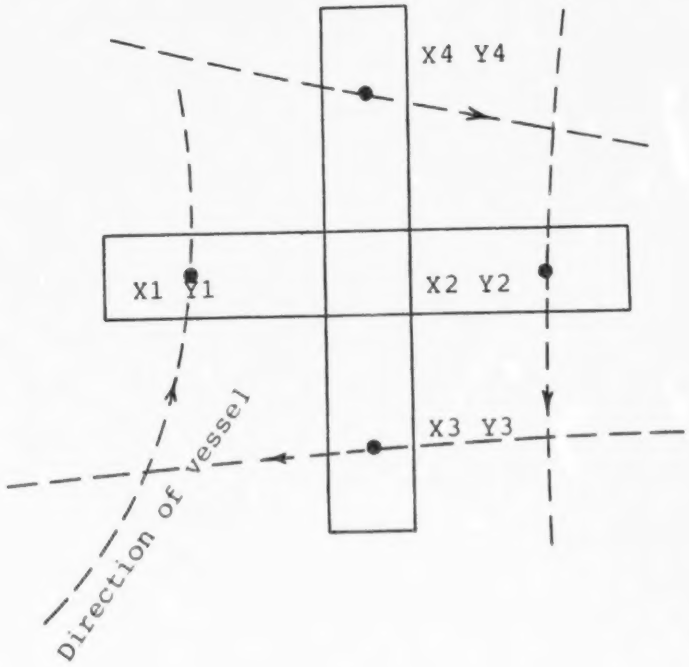
The above procedure of compiling numerous runs over the targets will be difficult because of the problem of keeping the vessel directly over each point with an accuracy of 1 to 2 metres. This problem may be solved somewhat by using a taut wire system.

The taut wire system is a mechanical system where the inclination of a line under constant tension is measured and transmitted electrically to the system using the position reference system (Morgan, 1978). The basic elements of the system are illustrated in Figure 6-22.


Steel rail
1-2 m.
1-2 m

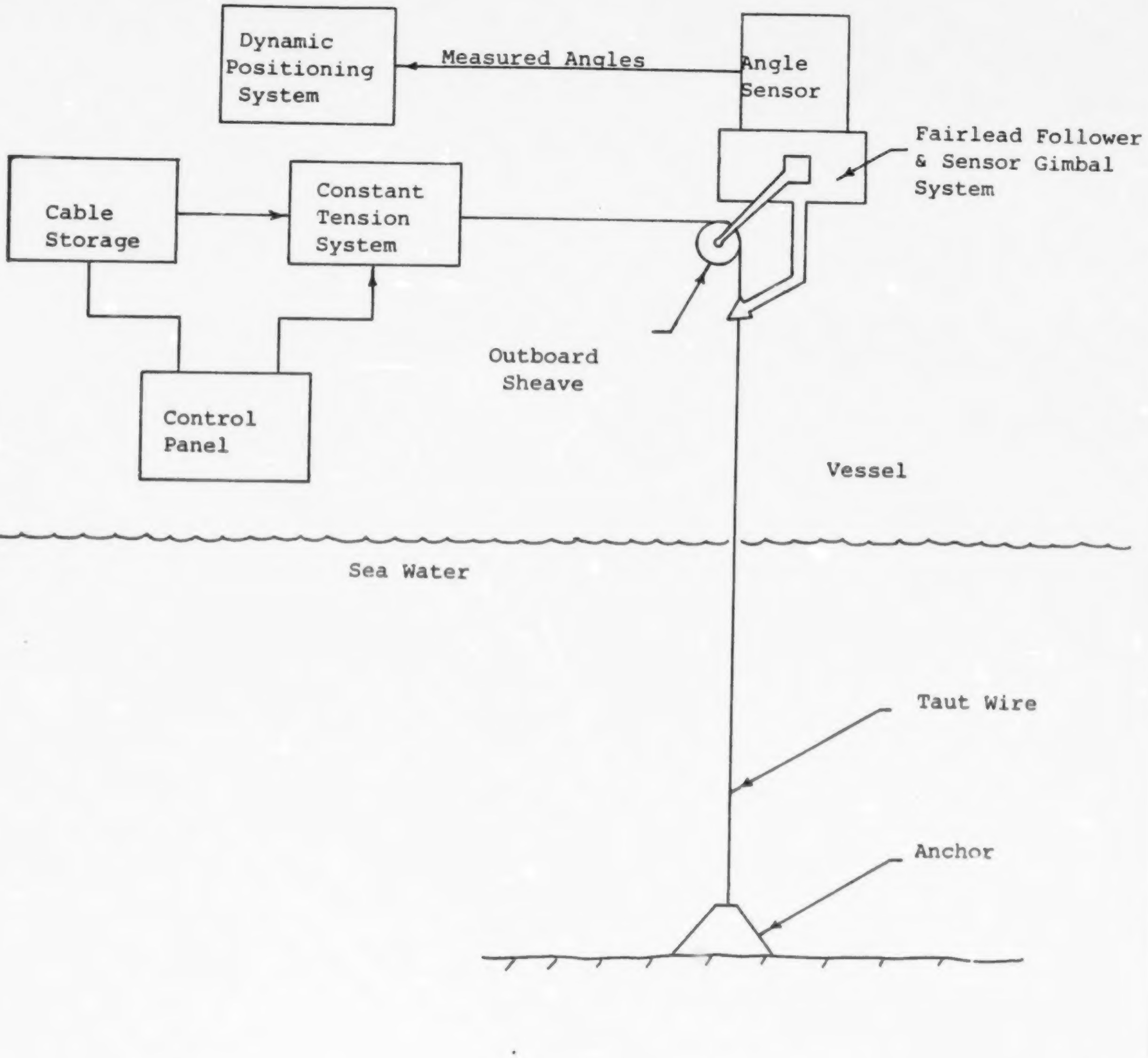
Target Design for Grid Points

Figure 6-20


X4 Y4
X1 Y1
X2 Y2
X3 Y3
Direction of vessel

DATA COLLECTION FOR PRECISE LOCATION OF TARGET

Figure 6-21


Dynamic Positioning System
Measured Angles
Angle Sensor
Fairlead Follower & Sensor Gimbal System
Cable Storage
Constant Tension System
Outboard Sheave
Control Panel
Vessel
Sea Water
Taut Wire
Anchor

ELEMENTS OF TAUT WIRE SYSTEM

Figure 6-22

In using this system, the wire would be attached to each target point. The vessel would be positioned directly over the point by minimizing the angle recorded by the taut wire system. This will then ensure that the vertical reading from the sounder is coming directly from the target point.

In addition to the error sources described above for the radio positioning and echosounder systems, the cable weight and drag caused by current will cause errors in the system which must be taken into account.

The wire would have to be attached to each target point by a diver or by using a submersible vessel. This will make the procedure very time consuming but it is an obvious necessary step in using the taut wire system.

Application and Analysis.

In utilizing the sea surface system, a vessel would travel over the study area collecting information on a continuous basis. The assumption must be made that each grid point within the area would be marked with some permanent device or target which will cause a well defined pulse from the echosounder.

As the survey vessel travels over the area in a regular pattern, X, Y, Z information is being recorded continuously. As the sounder trace for each point is recorded (Z), the X, Y information can be related directly to this (radio navigation system).

This survey would be performed at regular intervals and the X, Y. Z values for the points computed and compared with the data gathered in previous runs.

As many precautions would be taken as possible to try and ensure the utmost accuracy with this system. The shore stations would be surveyed very accurately. They would be located in the optimum locations to ensure the best angle of intersection (i.e. 90°). A high frequency system would be utilized which gives the best accuracy. The most accurate sounder with a narrow beam transducer would be utilized along with a heave compensator to determine the movement of the vessel caused by wind and wave action. Tidal information would also be recorded as accurately as possible as well as pressure, temperature and salinity in the area to determine a very accurate propagation velocity for the depth sounder. The taut wire system may also be utilized. The pattern should be run two or three times to give some amount of redundancy to the measurements and under optimum weather conditions, especially calm seas. The accuracy of the above system is as follows:

$X, Y = \pm$ 75-150 cm.
$Z = \pm$ 10 cm.

Any reduction of the above specifications will cause the accuracy to decrease.

In addition to the determination of the position of the grid points, a high density bathymetric survey can be run in conjunction with the above survey. A bathymetric chart will be produced based on the data collected at regular intervals and the results overlayed and compared to try and isolate any anomalies or changes that may have occurred as a result of subsidence.

Since there is usually movement of the sea bottom sediments caused by the motion of the sea, it may be difficult to isolate the reason for the changes in the bathymetry to mine induced subsidence only.

In order to increase the accuracy of the sea surface system certain modifications and adjustments would have to take place under a research and development program. One of these areas is that of the frequency utilized by the radio frequency system. Since the range required is a maximum of 10 Km from shore, a system may be developed which utilizes a frequency higher than the microwave frequencies presently on the market. This will raise the accuracy level of the horizontal information obtained.

In addition to this, a program could be initiated which would review the entire echosounder approach. The echosounder was originally designed for the mapping of the seabed but accuracy requirements were not nearly as stringent as those required for this project. It appears that the only way to increase the accuracy is to narrow the pulse beam width as much as possible. At present, narrow beam transducers are large and cumbersome.

Laser technology is also being developed for the compilation of bathymetric data but, again, from the point of view of acquiring data with a suitable accuracy for seabed mapping purposes. This technology is presently being developed where the information is acquired using an aircraft or helicopter. Present accuracies in the Z component are around 30 cm. The range of the system is limited to 20 to 30 metres in depth during the day and 50 metres at night. A research and development program could be put in place which would include the development of laser technology as a means of acquiring Z value data for mine subsidence monitoring purposes. This could include development of a shipboard system, upgrading the accuracy and extension of the range.

Cost

The capital cost for the purchase of the equipment required for the above application is in the order of $275,000. This includes the high frequency radio positioning system, the sounding system (including heave compensator), the computer system (including required interfaces), temperature, pressure and salinity probes, tidal gauges, the telemetry hardware required to transmit this data from the probes and gauges to the survey vessel and the software development required for this specific project. It does not include the fabrication of the grid points which would be fixed on the seafloor.

Table 6-6 is a breakdown of the cost based on type of equipment. The equipment described is also available for commercial lease and because of the relatively infrequent utilization of the equipment this may be the preferred route to take instead of the purchase of equipment.

Operating costs for each survey would run approximately $35,000.00 based on a five day survey. This includes equipment rental, personnel costs, survey vessel and other miscellaneous expenses.

Post Processing and Presentation

After the collection phase, all data will be processed and the final coordinates calculated for each grid point. Corrections will be made concerning the propagation velocity (temperature, pressure and salinity data), heave compensation information for the survey vessel and tidal conditions. A rigorous least squares adjustment is performed and the final coordinates calculated along with statistical information including the size of error ellipses for each station. A plot will also be generated showing the adjusted position of each of the grid points and other information which may be requested by the client. A high quality bathymetric chart of the area can also be produced showing contours and depth information. Each time a survey is completed, this information can be generated and comparisons made to highlight the magnitude of changes in the X, Y, Z values for each of the grid points.

Figure 6-22A depicts a flow chart of a typical navigation system as described above. Also included are samples of a high accuracy contour plot with auxiliary information generated and presented such as profile and perspective views (Figures 6-22B, 6-22C and 6-22D).

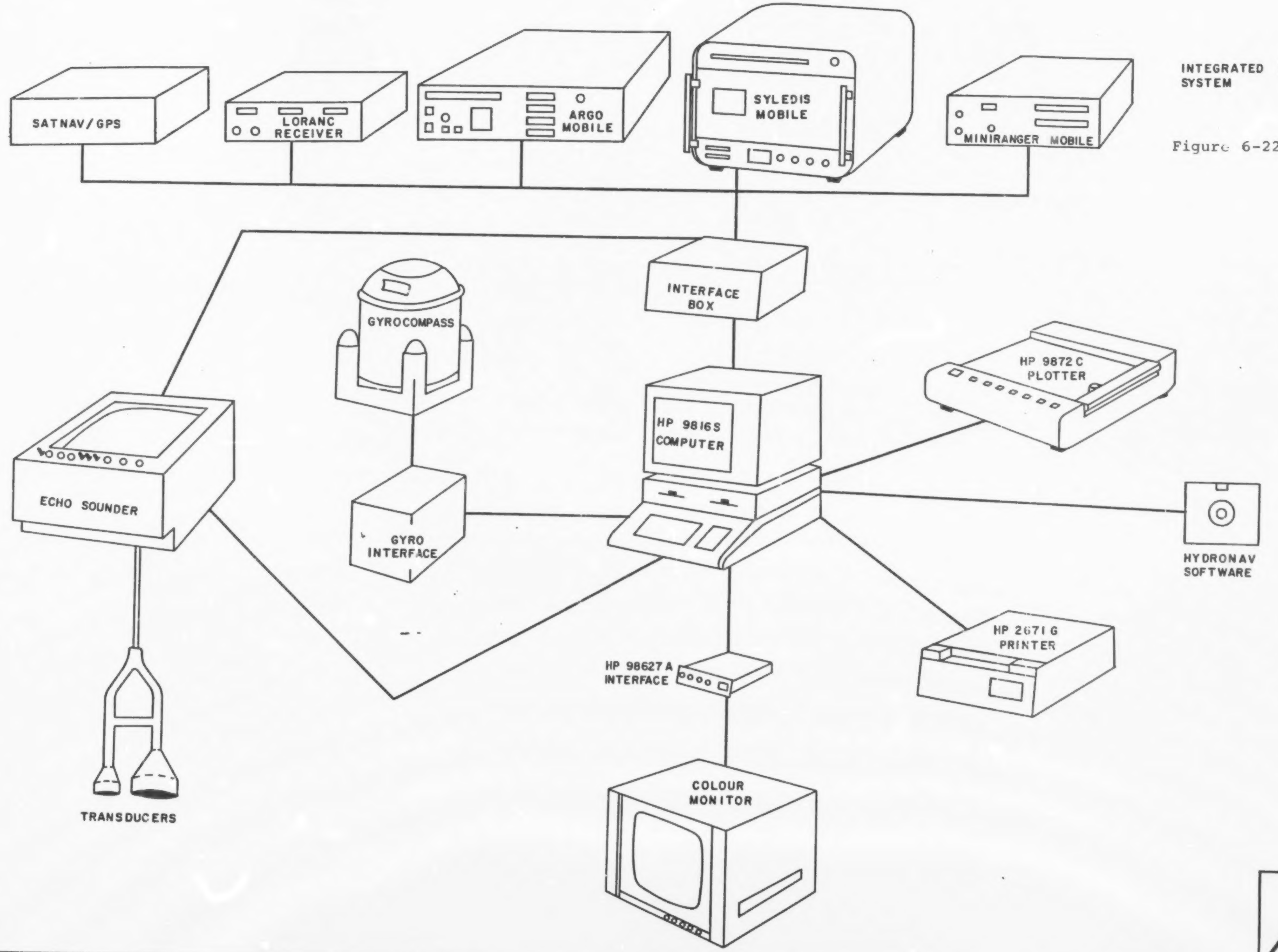
Equipment	Capital Cost
Radio Positioning System	$80,000.00
Echo Sounder	41,000.00
Heave Compensator	50,000.00
Computer, printer, interfaces	20,000.00
Plotter	8,500.00
Temperature, pressure, salinity probes	10,000.00
Tide Gauges (two)	62,000.00
Telemetry Hardware	50,000.00
Total Cost	$276,500.00

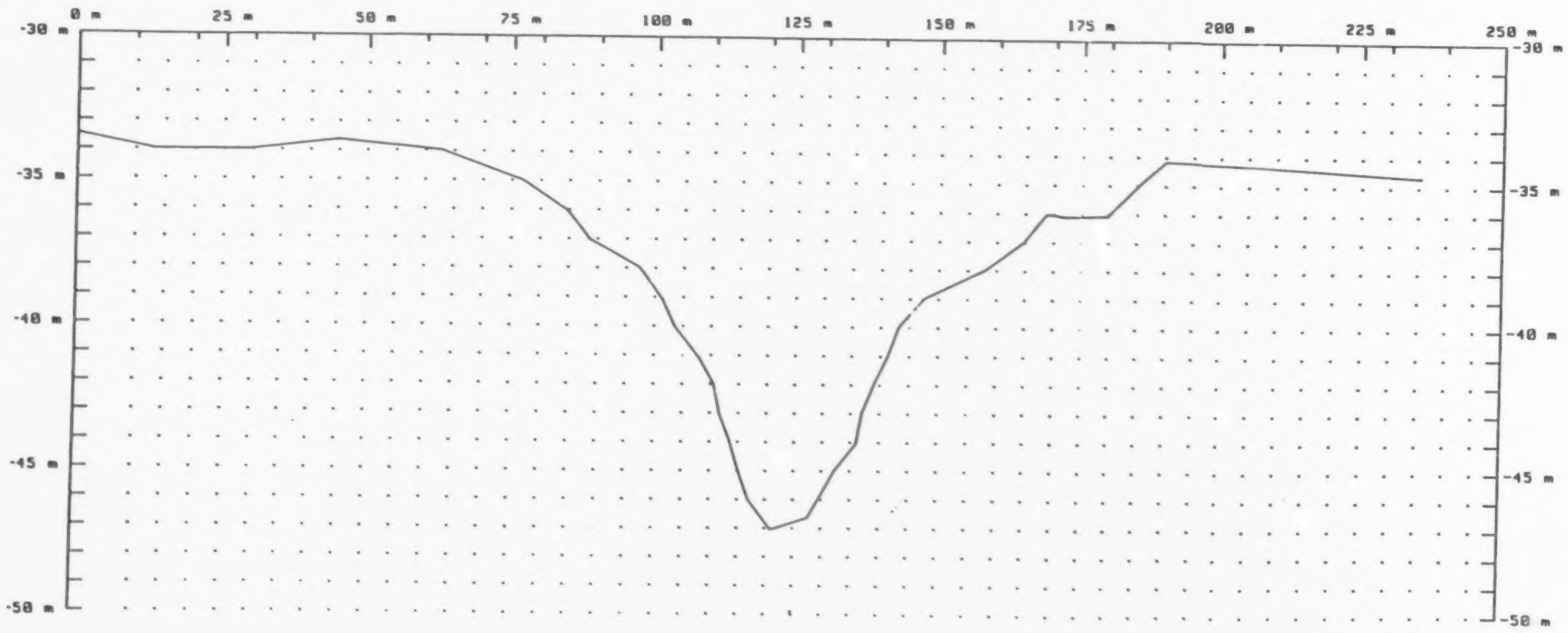
Capital Cost - Sea Surface Equipment

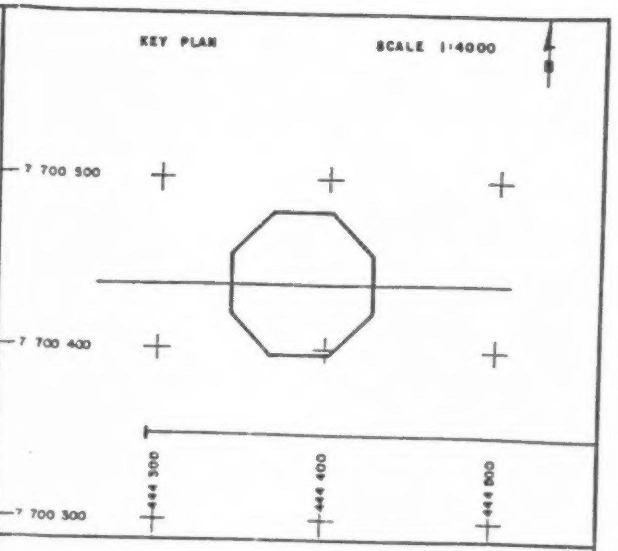
Table 6-6

INTEGRATED NAVIGATION SYSTEM

Figure 6-22A


SATNAV/GPS
LORANC RECEIVER
ARGO MOBILE
SYLEDIS MOBILE
MINIRANGER MOBILE
INTERFACE BOX
GYROCOMPASS
HP 9872 C PLOTTER
HP 9816S COMPUTER
ECHO SOUNDER
GYRO INTERFACE
HYDRONAV SOFTWARE
HP 2671 G PRINTER
HP 98627 A INTERFACE
TRANSDUCERS
COLOUR MONITOR



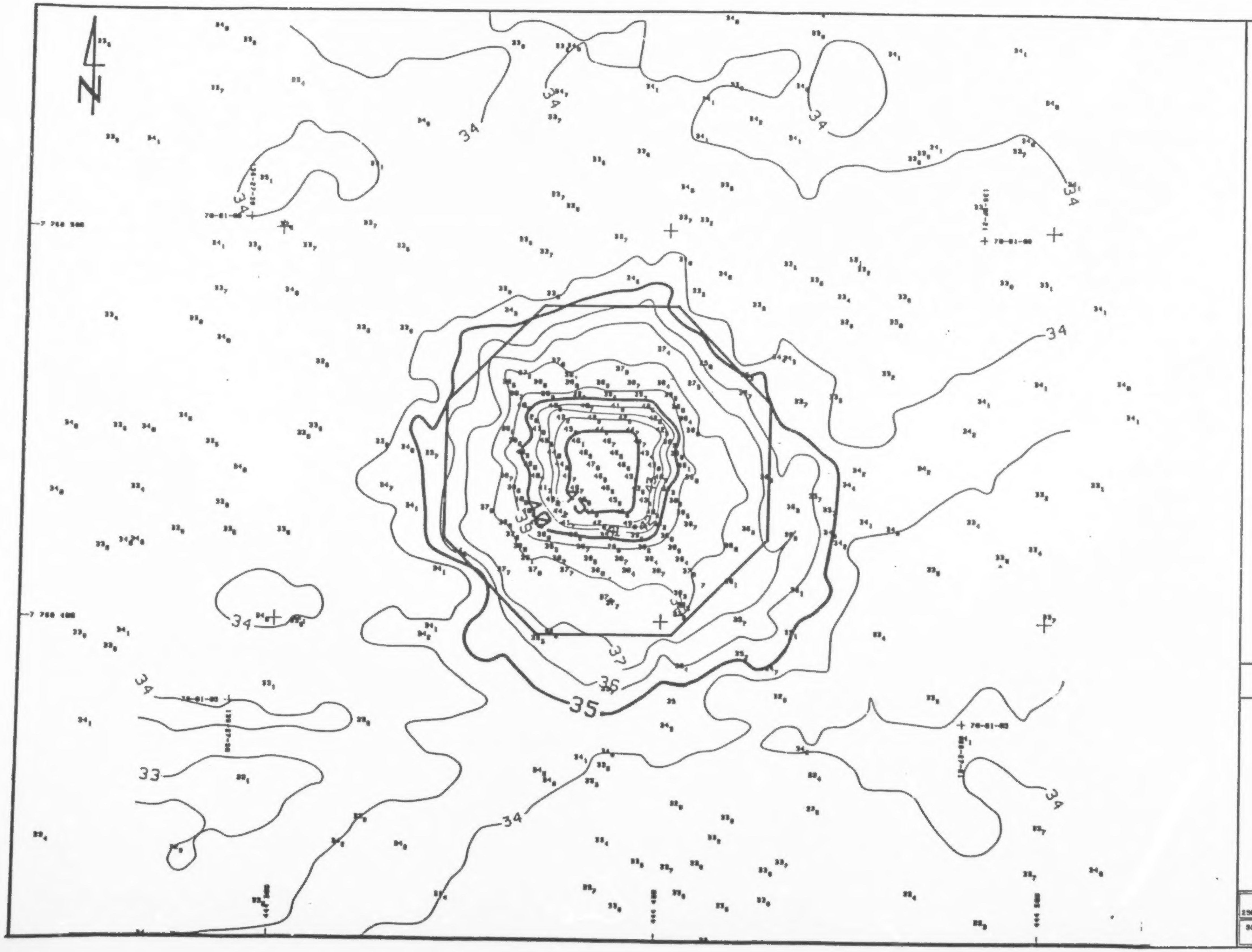

KEY PLAN
SCALE 1:4000
7 700 500
7 700 400
7 700 300
444 300
444 400
444 500

W-E CROSS-SECTION
SHOWING
MINE SUBSIDENCE

FIGURE 6-22B

Canadian Survey Consultants
25C Starlite Gallery, Bayers Road Shopping Centre Halifax, Canada

H SC. 1:2000 V SC. 1:200	DATE: SEPT 28,1984	JOB No.:	DWG. No.:

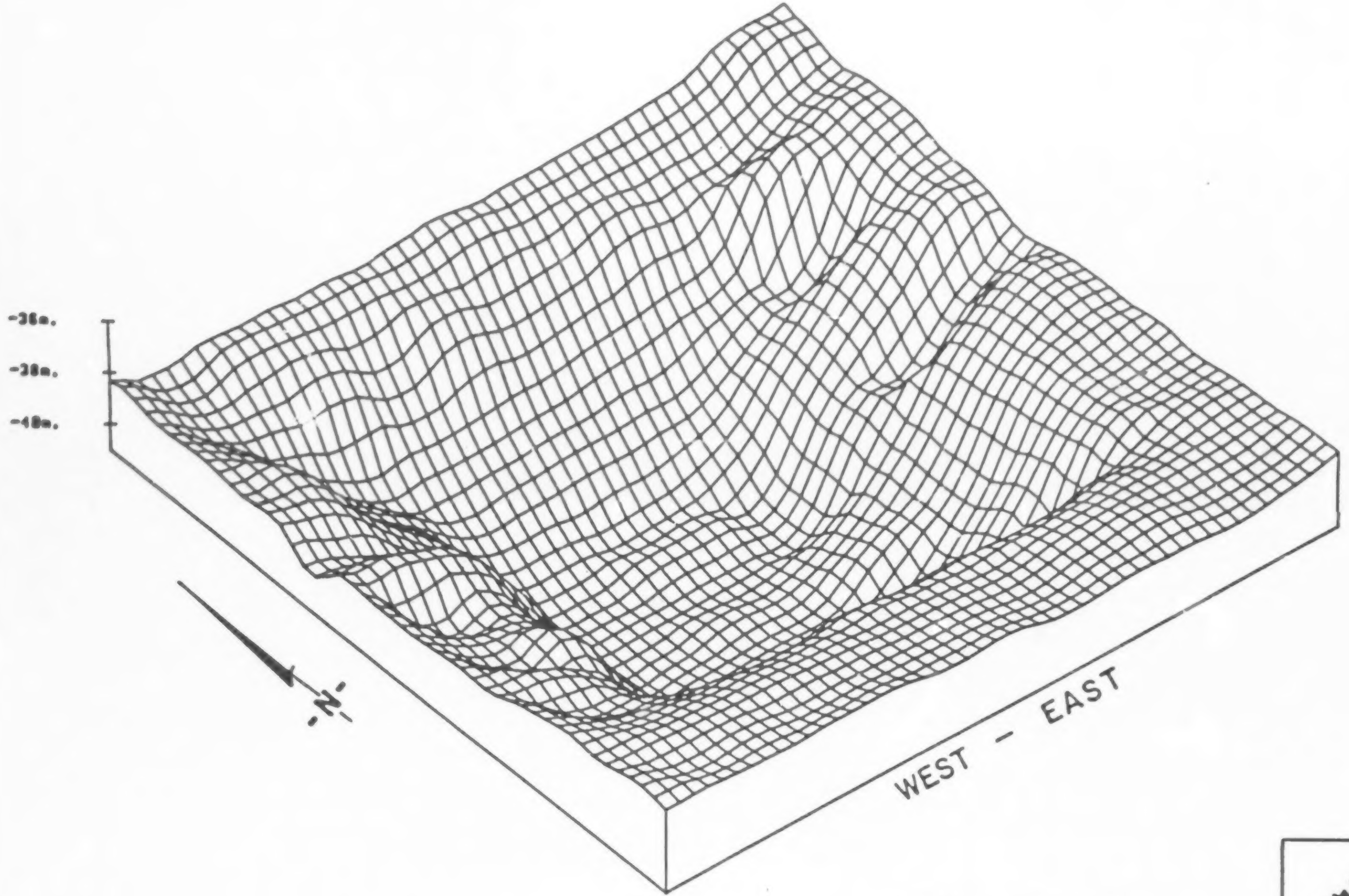

N
34
33
35
36
37
40
45
7 760 500
7 760 400
78-01-08

CONTOUR PLAN
SHOWING
MINE SUBSIDENCE

FIGURE 6-22 C

Canadian Survey Consultants 236 Starlite Gallery, Bayers Road Shopping Centre Halifax, Canada			
SCALE: 1:1000	DATE: SEPT. 28,1984	JOB No.:	DWG. No.:

PERSPECTIVE VIEW OF MINE SUBSIDENCE


-36m.
-38m.
-40m.
N
WEST - EAST

VERTICAL EXAGGERATION : 40X

FIGURE 6-22D

Survey Vessel.

Although the project area is very close to shore (within 15 Km) a vessel of substantial size is required. The reasons for this are:

- stability
- space required for on-board instrumentation and operating personnel.
- space required for deployment and retrieval of instrumentation and buoys.

A vessel of at least 30 metres in length would fulfill the basic requirements for this project. A boom crane capable of lifting and deploying equipment is a necessity as well as adequate space for on-board equipment which would include receivers and other electronic navigation equipment, computers, plotters, antennas and transducers.

Additional equipment that may be required include geophysical and geotechnical instrumentation, cameras and diving equipment. If a submersible is utilized, the vessel must be capable of storing, deploying and retrieving it.

A vessel of this type can be leased for approximately $4,500.00 per day, including crew, fuel, oil and other miscellaneous expenses. This is the operating day charge based on short term lease. If the charter is based on a longer time frame, the rate could be reduced. Stand-by rates for a vessel of this type would be approximately $3000.00 per day.

If the project specifications called for measurements every week for ten weeks, the vessel would be chartered for the full ten weeks whether it was used every day or not. If the specifications called for measurements every three months, it could be chartered only as required, probably on a minimum of ten days per charter even though the survey may take only a small portion of that time.

Subsea Systems

These acoustic positioning systems work basically in an underwater environment. As in the surface systems, there are a number of different systems available with the same hardware and software qualities and basic configurations.

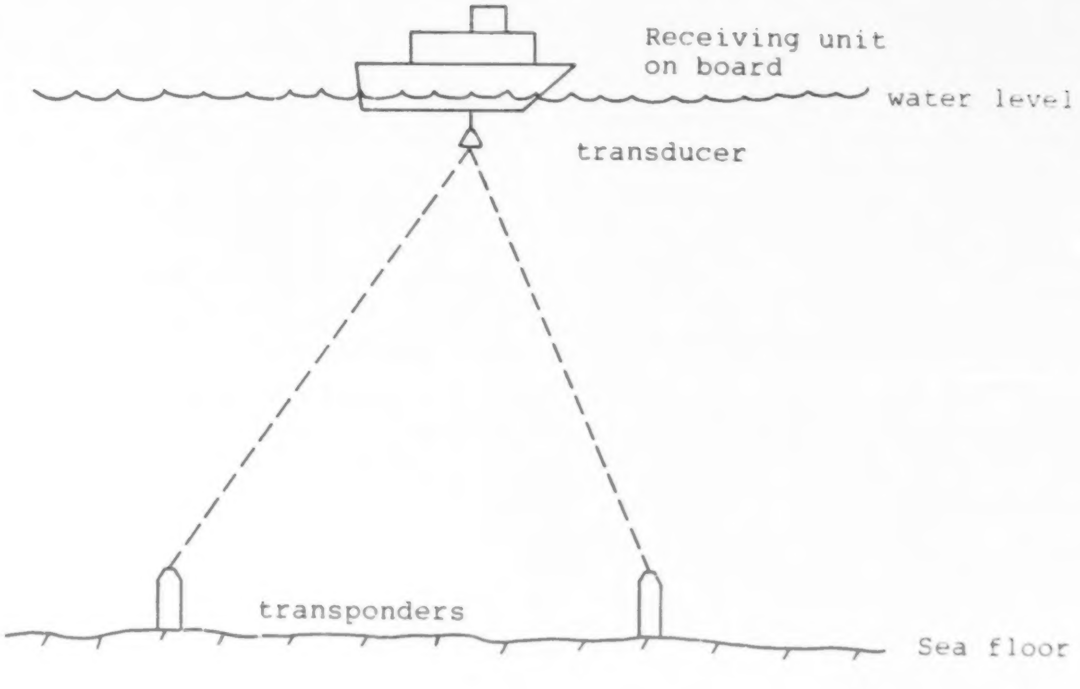
Description.

The normal configuration for an acoustic positioning system includes a receiving unit and transducer (usually on board a survey vessel) and a number of transponders which are deployed around the perimeter of the working area (Figure 6-23).

The principle of measuring ranges is the same as the surface radio positioning systems where a pulse of known frequency is transmitted by the unit on board the vessel and received and returned by each of the transponders. The time is measured and the range derived from this information. Frequencies range from low (8-16 KHZ) to medium (18-40 KHZ) to high (54-108 KHZ). The range of each system based on frequency and water depth is shown in Table 6-7.

The transponders act as control points and their relative and absolute position must be known. This is accomplished by running through a "calibration" routine where the ship steams through the area recording many slant ranges to the transponders. These ranges are then processed by a computer to obtain the accurate geometry of the array. This results in a "relative calibration" where the location of the transponders are known relative to each other.

In order to accomplish absolute calibration, the vessels position must be known based on some coordinate system (e.g. UTM). This dictates that a radio positioning and/or satellite system be on board the vessel and integrated with the acoustic system. This then provides absolute coordinates for


Receiving unit
on board
water level
transducer
transponders
Sea floor

ACOUSTIC POSITIONING SYSTEM

Figure 6-23

the transponders when the calibration is being done. This is necessary for the application since the vessels position relative to the CBDC survey grid or the provincial survey grid system must be established.

Some systems are available where the transponders contain a micro-processor which allows them to range directly between each other. This results in a more accurate calibration and distance information.

The equation for the derivation of the range is:

$r = v.t/2$ where r is the range
v is the propagation velocity
t is the time travelled by the pulse.

The velocity must be established as accurately as possible because of the high accuracies required in subsidence measurements. The velocity in sea water is related to temperature, salinity and pressure. Therefore, detailed information concerning these three parameters must be known over the work area. This has been previously described under Sea Surface Systems.

Table 6-8 shows the horizontal accuracies attainable using different frequencies.

Because changes in position over time are being monitored, the repeatability factor is the most important in an acoustic system.

Using the above information and the data in Table 6-7 the best system to utilize would be a high frequency system. The range however, for this system is limited to 800 m. Ranges in excess of this are required as noted in Table 6-1 which may have a tendency to increase the repeatability errors.

Table 6-8 refers only to the horizontal (X, Y) position. The vertical component (Z value) is derived by a pressure sensor housed in the transponders on the seabed. These sensors determine the depth or amount of water above them. By comparing any changes in differences in depth between the points within the area of influence and the points outside the area of influence, very accurate Z component information can be obtained and small movements in this direction detected. Manufacturers state that the accuracy of measurements for these sensors are in the order of ± 0.5 - ± 2 cm.

Table 6-7

Range of Acoustic Positioning Systems

Water Depth	LF	MF	HF
10-50 m	1-5 Km	1-5 Km	800 m
50-100 m	3-8 Km	3-7 Km	1500 m
100 m plus	7-10 Km	5-8 Km	1500 m

Table 6-8

Performance of Acoustic Systems

	LF	MF	HF
Repeatability	± 0.3 m	± 0.2 m	± 1 cm
Accuracy	± 1.5 m	± 1.0 m	± 4 cm

These figures appear to be somewhat optimistic. In a project conducted in the North Sea (Kelland, et al, 1983), the relative accuracy in height utilizing these pressure sensors was in the order of ± 3 cm in 150 m of water. Voltage, temperature sensitivity and drift of the sensors were determined and applied.

Application and Analysis.

An acoustic positioning system could be applied to the mine subsidence monitoring program as described below:

A number of transponders/transducers would be set up outside the monitoring area to act as control points. These would be assumed to be on stable ground which would not be influenced by any subsidence which may be occurring.

These control points would be capable of the following:

- being interrogated by a surface receiver for the purpose of absolute orientation,
- interrogating the units within the area of influence to determine range information,
- determining the water depth,
- determining pressure, temperature and salinity information,
- telemetrying the information to a surface buoy which would telemeter to a shore station or transfer of data to shore by a hard wire link,
- interrogating the other control points.

Points established within the area of influence would be capable of the following:

- being interrogated by the control points to determine range information,
- determining the water depth,
- determining pressure, temperature and salinity information.

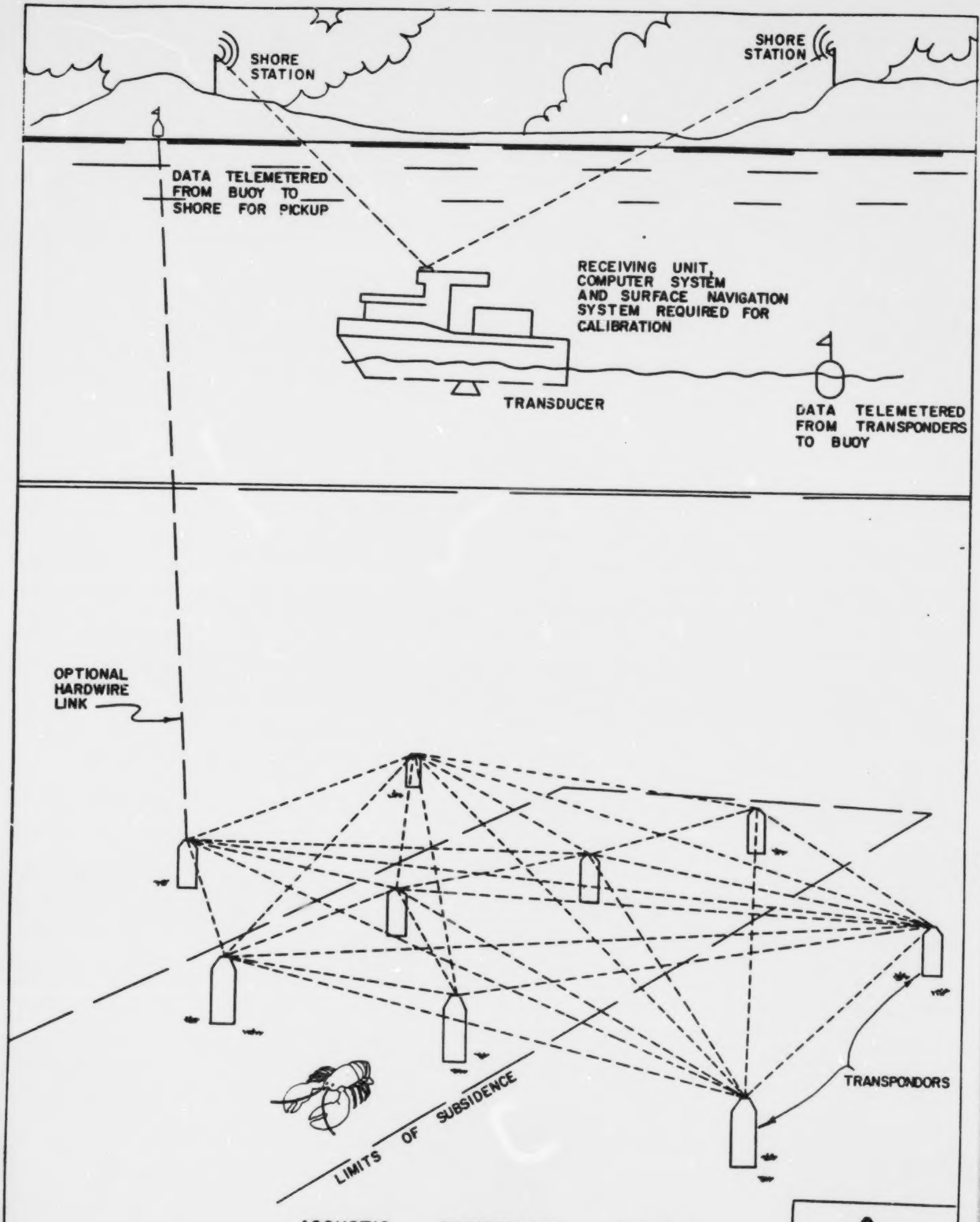
Information would be recorded on any user determined interval. One scenerio is that data be recorded once every 24 hours. This information would be telemetered to the surface and through to the shore station. It would then be collected from time to time and processed. Very precise coordinates (X,Y,Z) would be determined for each of the points and any change in coordinates (X, Y, Z) highlighted.

Figure 6-24 shows a proposed layout of an acoustic system utilized for mine subsidence monitoring.

Because instrumentation (transponders) will be left at each point, the main criteria is that they be housed and protected in some permanent casing. It should also be possible to remove the transponder and replace it later in the exact same spot. A mechanism could be fabricated to provide for this. The housing unit would also have to be secured to the sea bottom.

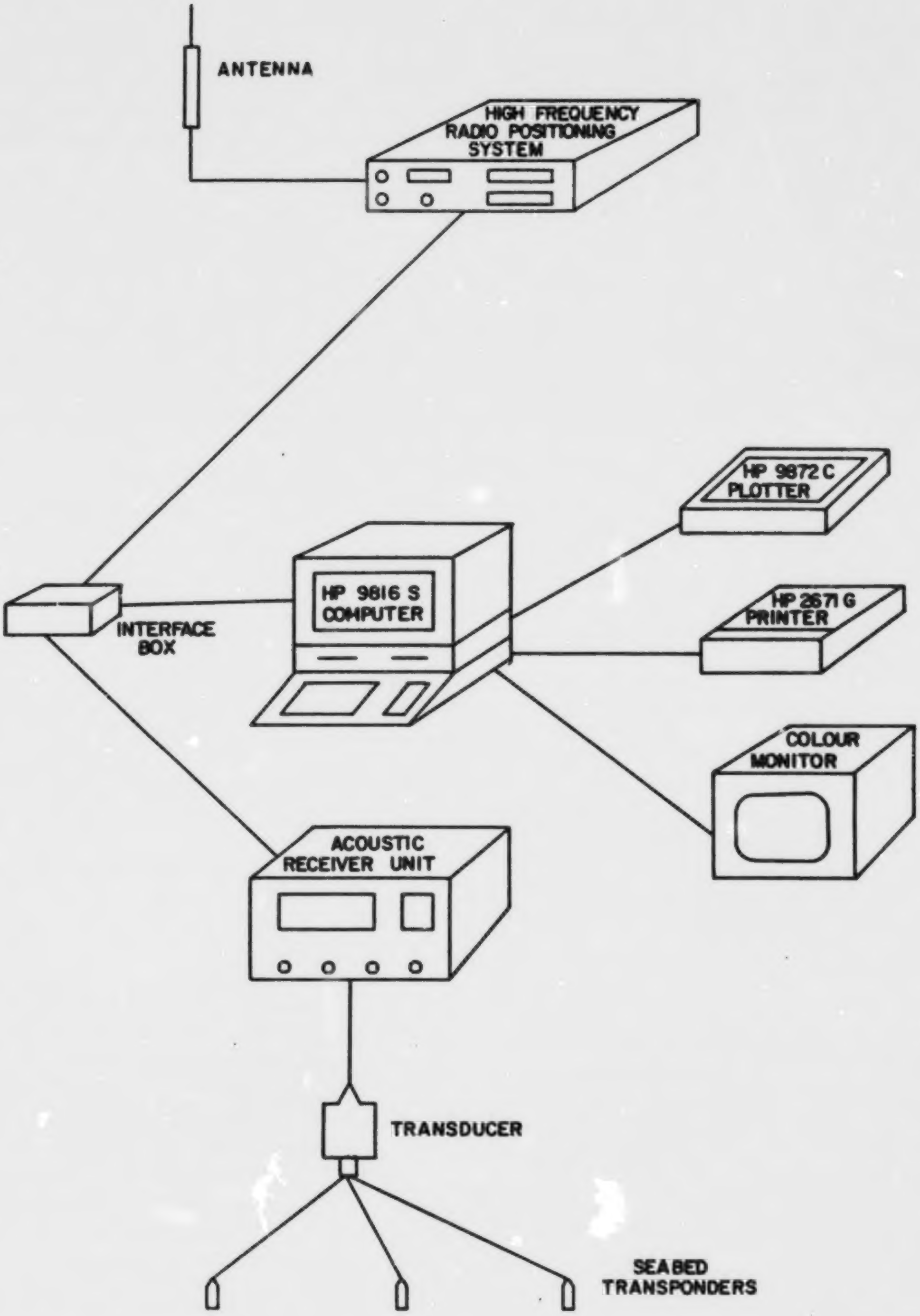
One problem with this type of system is that equipment must remain on the seabed at all times. There is a certain amount of drift ice in the area throughout the winter months which could destroy the transponders and telemetry system (Nordco, 1981). It may be advisable to suspend operations during this time to ensure that no damage is done to the equipment and measurement points.

Figure 6-25 presents a hardware flow chart of the on board portion of the system, Figure 6-26 depicts the Data Collection system and Figure 6-27 outlines the Post Processing system. This equipment is available for lease on an "as required" basis. The sea surface system will be used only to deploy the hardware and initialize the acoustic system. It will also be needed when any site visit is required such as repair and maintenance trips or suspension due to ice conditions. A portion of the acoustic system will be a permanent installation (the bottom-mounted transponders). These will be deployed on the bottom and remain there for the length of the project unless changes are required in the battery packs. Life of the batteries varies depending on the amount of interrogation taking place. Battery life of one year is practical for this project.


SHORE STATION
SHORE STATION
DATA TELEMETERED FROM BUOY TO SHORE FOR PICKUP
RECEIVING UNIT, COMPUTER SYSTEM AND SURFACE NAVIGATION SYSTEM REQUIRED FOR CALIBRATION
TRANSDUCER
DATA TELEMETERED FROM TRANSPONDERS TO BUOY
OPTIONAL HARDWIRE LINK
TRANSPONDORS
LIMITS OF SUBSIDENCE

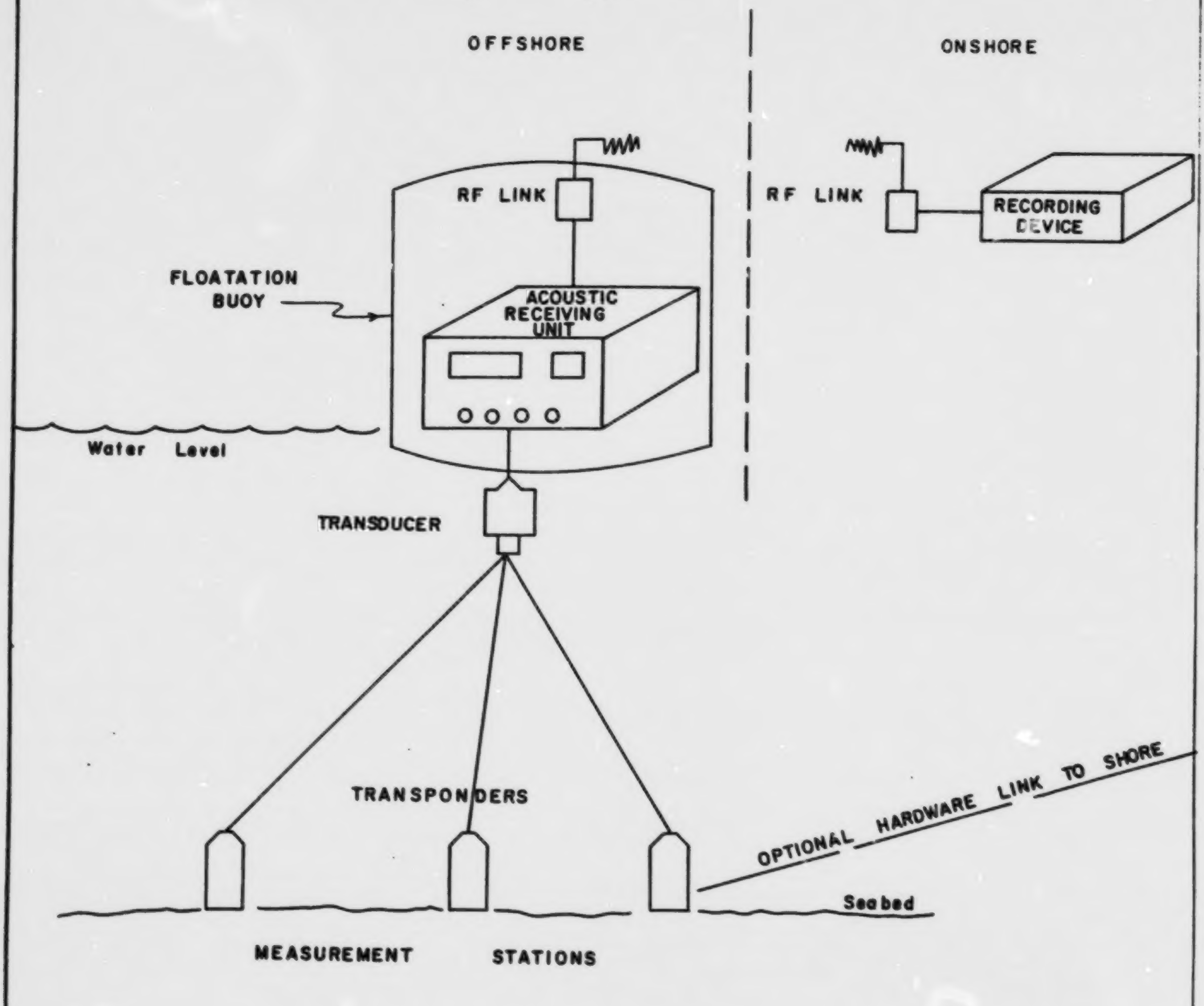
ACOUSTIC POSITIONING SYSTEM

Figure 6-24


ANTENNA
HIGH FREQUENCY RADIO POSITIONING SYSTEM
HP 9872 C PLOTTER
HP 9816 S COMPUTER
HP 2671 G PRINTER
INTERFACE BOX
COLOUR MONITOR
ACOUSTIC RECEIVER UNIT
TRANSDUCER
SEABED TRANSPONDERS

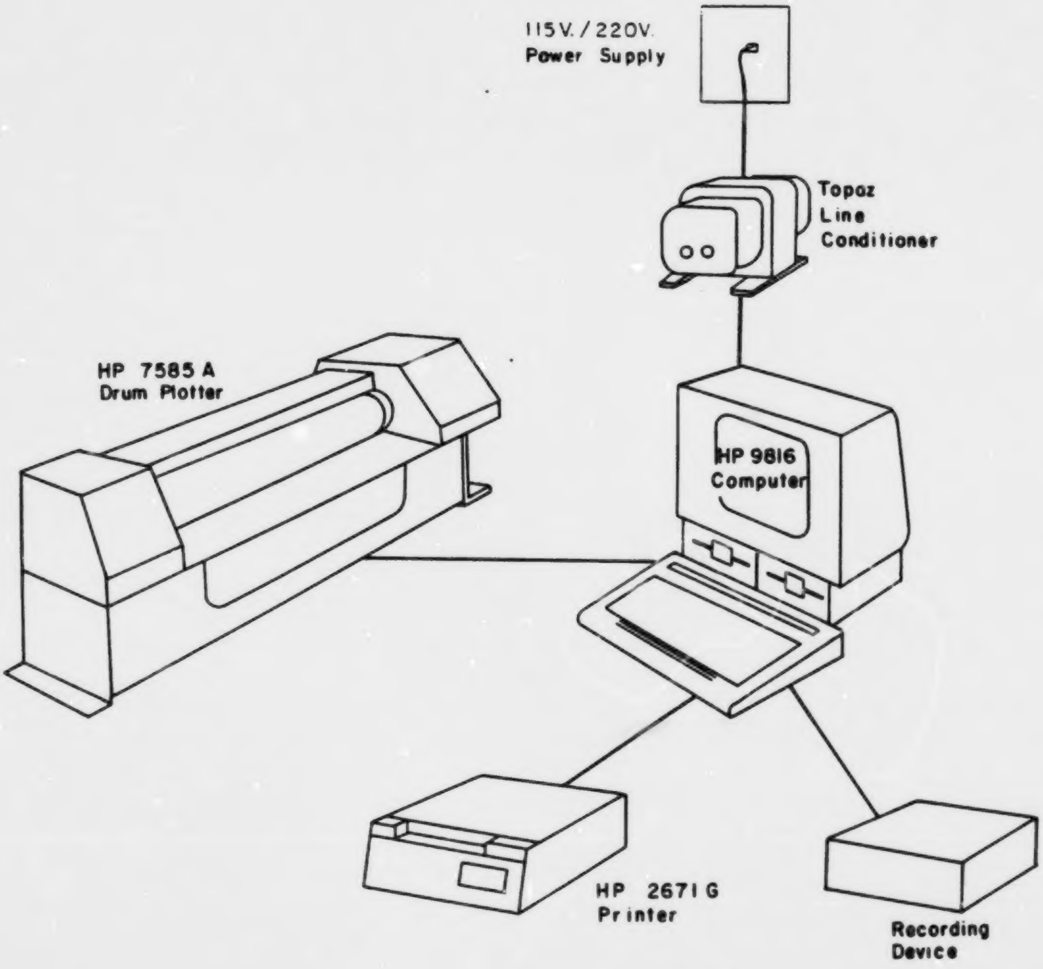
INTEGRATED RADIO POSITIONING AND ACOUSTIC POSITIONING

Figure 6-25


OFFSHORE
ONSHORE
RF LINK
RF LINK
RECORDING DEVICE
FLOATATION BUOY
ACOUSTIC RECEIVING UNIT
Water Level
TRANSDUCER
TRANSPONDERS
OPTIONAL HARDWARE LINK TO SHORE
Seabed
MEASUREMENT STATIONS

HARDWARE FLOWCHART - DATA COLLECTION SYSTEM

Figure 6-26


115V./220V.
Power Supply
Topaz
Line
Conditioner
HP 7585 A
Drum Plotter
HP 9816
Computer
HP 2671 G
Printer
Recording
Device

POST PROCESSING SYSTEM

Figure 6-27

This system comes close to the optimum requirements for monitoring mine subsidence. If required, a program of research and development could be initiated, the objective of which would be to further refine the accuracy of the system to the sub-centimetre level. Because the present accuracy is in the order of 1-4 cm., it is very conceivable that this could be achieved in a reasonably short amount of time.

The development of acoustic navigation has progressed very rapidly in the past five to ten years and mainly as a result of engineering applications in the offshore oil and gas industry. The system certainly has the potential to become the one most likely to develop quickly and efficiently as a tool for monitoring mine subsidence in a sub marine environment.

Cost.

The purchase of an acoustic positioning system as described above would include two receiving units, bottom-mounted transponders and a telemetry and recording system. Also required would be a post processing system. The entire hardware package would be "added on" to the sea surface system described previously. Table 6-9 outlines the cost breakdown for this equipment.

The equipment is also available for lease, the price of which is usually based on a percentage of the capital cost per month. A rough estimate of the leasing costs for the above systems is broken down in Table 6-10.

Table 6-11 is an estimate of the equipment costs involved in a subsidence monitoring program using acoustic positioning systems and running over a time period of one year. Each individual cost is based on a short term day rate figure. This could be reduced substantially, especially for the data collection component because of the long term lease that is required.

Table 6-9

Capital Cost - Acoustic Positioning System

Item	Cost
Sea Surface System	176,000.00
Acoustic Receiver and transducer	50,000.00
Bottom-mounted transponders (48 stations at 8625 per station)	414,000.00
Telemetry and Recording System	100,000.00
Post Processing System	50,000.00
Total Cost	$790,000.00

Table 6-10

Leasing Costs for Different Systems

System	Cost per Month.
Sea Surface	$17,600.00
Data Collection	40,000.00
Post Processing	5,000.00

Table 6-11

Equipment Costs for Subsidence Monitoring Program

Item	No. of Days	Cost
Sea Surface	50	$29,333.00
Data Collection	365	486,666.00
Post Processing	30	5,000.00
Survey vessel	50	225,000.00
	Total Cost	$745,999.00

Post Processing and Presentation.

Data is recorded at some user defined interval telemetered to the surface and then to shore where it is stored on disc or tape. Since the measurement of the range requires no human intervention or input once the system is in place, the frequency of generation of position can vary depending on client request. The system is capable of recording range information on a continual basis or some other user defined interval. This could be one hour, one day or one month depending on user preference.

At regular intervals, the data will be collected and processed. A rigorous least squares adjustment will be performed and X, Y, Z values will be generated for all points with statistical data including error ellipse information. Any changes in values for the points will be highlighted as a possible indication of subsidence. All factors will be taken into account including temperature, pressure and salinity.

The products envisioned are the final adjusted coordinates of each of the grid points (X,Y,Z) at each time interval, the statistical information associated with this (error ellipse information) and a plot depicting this information.

As time goes on and more data is collected, difference in coordinates for the same grid points will be shown and a plot over time showing the "movement" or change in coordinates for the grid points.

Survey Vessel

The survey vessel requirements for the deployment and calibration of an acoustic system are similar to the sea surface system. Adequate space for instrumentation is required as well as a boom crane for the deployment of certain equipment. Stability of the vessel, again is very important. The vessel should be at least 30 metres in length with the prices and other information similar to that previously described.

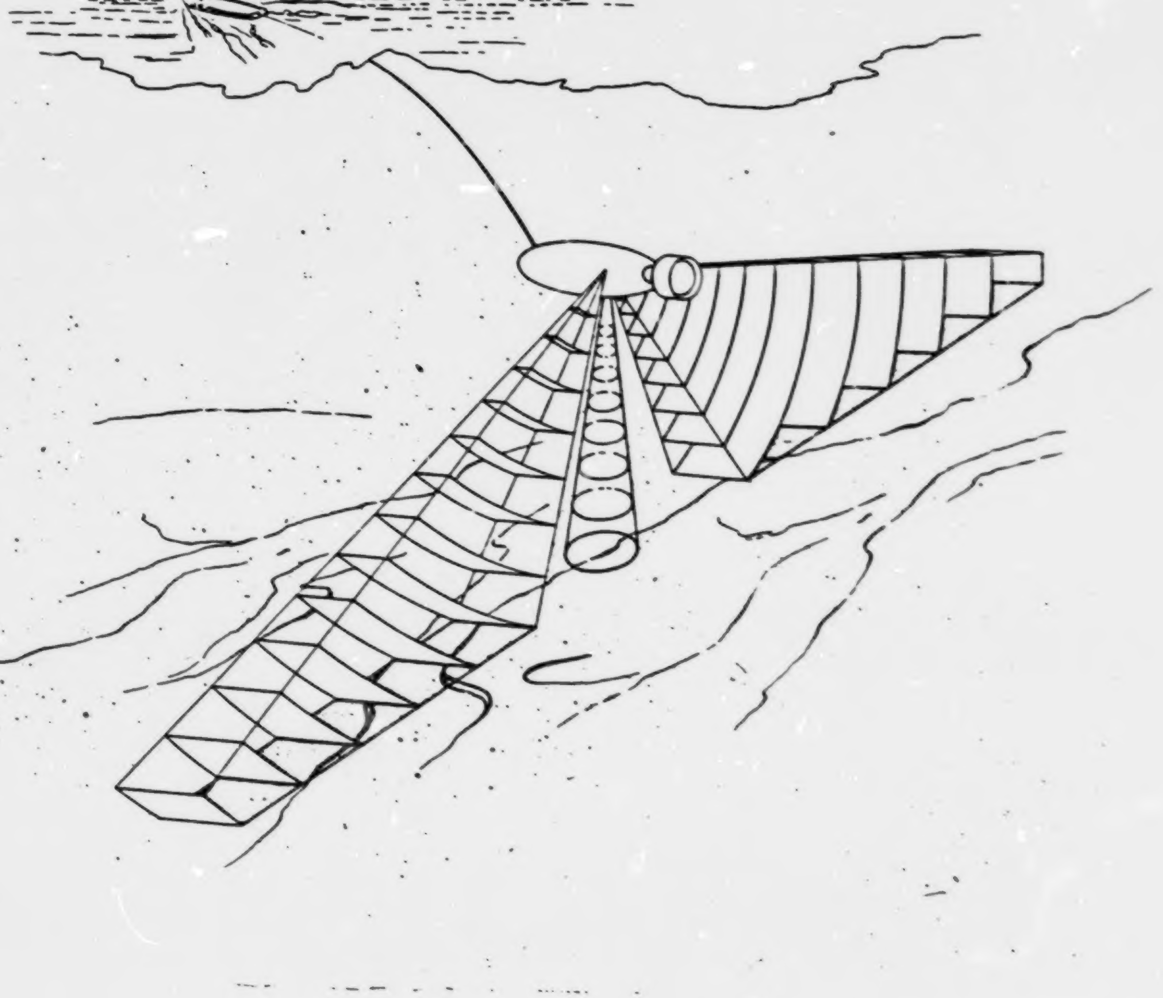
Geophysical Survey Systems

Description.

The more conventional use of geophysical surveys is for the delineation of the geology under the sea bed to try and isolate promising structures such as oil and gas deposits.

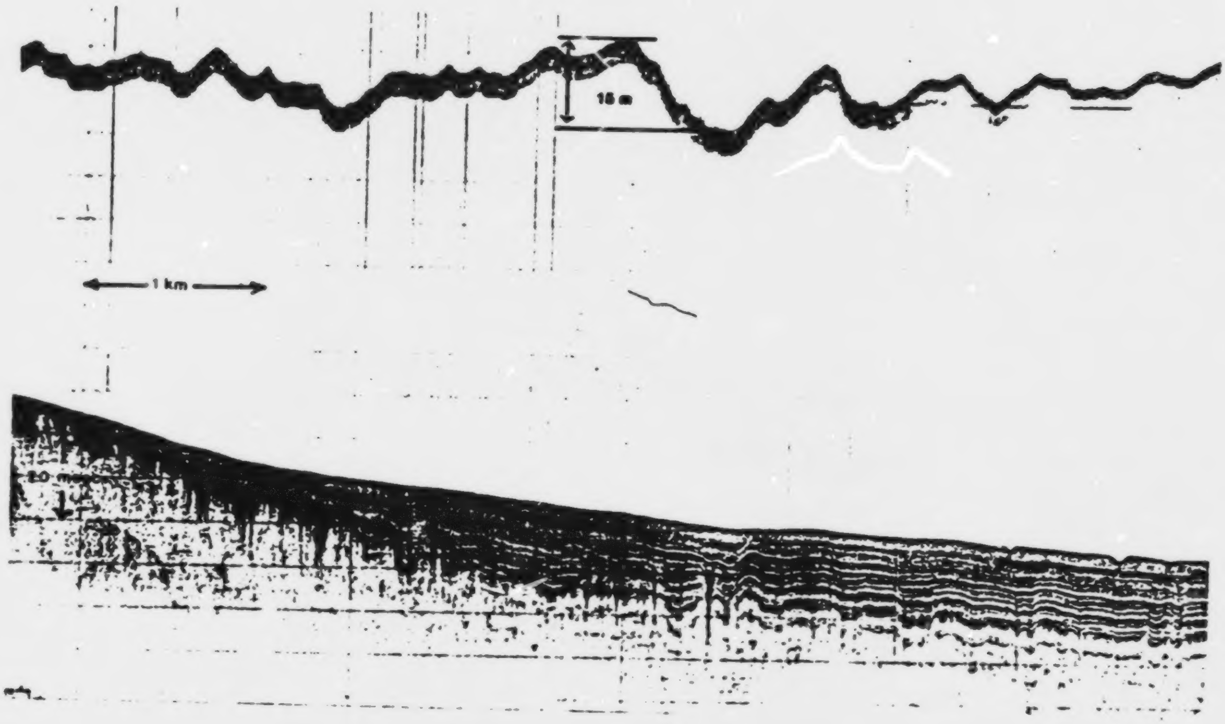
Those techniques that may be useful in a subsidence project are those classified as high resolution systems. These techniques will produce the following information; determine the nature of the seafloor topography and of the water sediment interface, determine the characteristics of the first 50 metres of sediment below the seafloor, identify shallow geological formations in the first 600 metres of sediment (Energy, Mines and Resources, 1982).

The main hardware components are Sidescan Sonar and Sub-Bottom Profiling. The combined effect of a high frequency beam shape and very short acoustic pulse enables the system to resolve details on seafloor micro and macro features from the differing strength of the acoustic returns. The principle is similar to the acoustic and echo sounding techniques described previously where an energy source generates a pulse of short duration, broad frequency spectrum, high energy and consistency. The sidescan sonar has a frequency range of 20-500 KHZ and the sub-bottom profiler 400 HZ-14 KHZ. The energy is usually generated from a source which is towed behind the survey vessel at some uniform distance above the sea floor (15-150 metres). Figure 6-28 depicts an energy source being towed behind a vessel and utilized for the acquisition of side scan sonar data. The display of reflection times and the amplitude of energy returns from the objects on the bottom, give a graphic presentation of their position and attitude. Figure 6-29 is a sample of a sub-bottom profile record showing different layers beneath the ocean floor.



SIDESCAN SONAR ENERGY SOURCE

Figure 6-28



SUB-BOTTOM PROFILE

Figure 6-29

Application and Analysis.

The results of a high resolution geophysical survey utilizing sidescan sonar and sub-bottom profiling in conjunction with accurate echo sounding will result in the following data.

- surficial distribution of sediments and bedrock
- location of outcrops and submerged objects
- topographical mapping
- sea bottom morphology
- sub-surface stratigraphic mapping
- ice scour depth in-filling aggregate and alluvial mapping
- high resolution topographic profiling
- bathymetry

The resolution of the above information is between 10 cm and 60 cm. The system must be positioned accurately using offshore navigation equipment such as that described under Sea Surface Systems.

The geophysical surveys could provide some useful information with respect to changes in structures and formations which may have occurred as a result of subsidence. Although the sidescan sonar and echosounder provides information about the seabed only, the sub-bottom profiler penetrates the seabed up to 60 metres. This could also provide some interesting characteristics and changes may be quite evident when reviewing data over a long time frame. The system would have to be tightly controlled to keep the positional accuracy below 1 metre in the X, Y component. It could also be controlled by definitive objects identified outside the subsidence area so that they can be considered stable. These "control points" could be placed on the seafloor and utilized to control the remainder of the information. This will ensure a very high order of accuracy. A complete geophysical survey would include all of the components described under the Sea Surface Section as well as all the components discussed in this section.

Another technique would be to utilize hydrophones which are deployed on the seabed to monitor any micro-seismic activity which may be occurring. Small movements (less than 1 cm) can be detected and located by utilizing numerous hydrophones over the area. Sound waves are produced by these small fractures within the ground and the hydrophones pick them up.

The magnitude of the sound is readily available but some empirical calibration procedure would have to be devised to compute the subsidence magnitude. This would be accomplished by the measurement or recording of similar sound waves over some area where the magnitude of subsidence can be readily measured.

All information would be recorded and a system devised for transmitting this data to shore. This would be either telemetry, hard wire or an acoustic release system.

A telemetry system would be the most convenient but it would necessitate a buoy/telemetry system on the surface of the ocean. This may be destroyed either by the drift ice or local fishermen. A hard wire link would avoid the problems of local fisherman but may still be destroyed by the drift ice. An acoustic release system would again, possibly be destroyed by drift ice. If the systems were demobilized during the winter months, this would alleviate any problems because of ice.

Cost.

The capital cost for a complete geophysical survey system including sidescan sonar and sub-bottom profiler is approximately $110,000.00. This cost would be added to the surface navigation system to provide a total navigation/geophysical system.

The hydrophone approach would involve approximately $50,000 in capital expenditures. The surface navigation and acoustic systems would be required for the deployment and positioning of the hydrophones.

Again this equipment is readily available under lease arrangement which would be the advisable approach since it would only be utilized for a small amount of time.

Post Processing and Presentation.

A graphic record is produced in any high resolution survey which will indicate different soil types and layers, the extent and location of bedrock and ice scars. By reviewing this data and overlaying from period to period, an indication of subsidence may show up on the record. The sismic data is recorded on magnetic tape which may be reproduced in graphic form at larger scales. This will help to provide a more detailed picture of the area of influence.

Survey Vessel.

The specifications for the survey vessel are the same as those previously stated. Since instrumentation will be towed by the vessel, more elaborate boom equipment may be required.

6.6 ANCILLARY APPLICATIONS

The Use of Divers and Submersibles.

In areas where the water depth is shallow, divers can be utilized to assist in the deployment of instrumentation and data collection.

The instrumentation to be placed on the sea floor must be precisely deployed to within a few metres of certain points. This will require continuous monitoring of position as the equipment is being placed on the bottom with the aid of an acoustic positioning system. It would be feasible for divers to physically transport the equipment to the bottom and assist in the placement to ensure that the locations are accurate and correctly placed over the appropriate panel.

As an alternative to setting up hardware at each of the target points described in the section on Acoustic Positioning, a diver could be utilized to transport the necessary hardware from one point to another in order to record the necessary information.

This has the advantage of being less costly for hardware purchase (the number of transponders would be considerably less) but the disadvantage is that information could be recorded only when the diver is on site. The flexibility in the collection and amount of data recovered would be limited.

A diver could also be utilized to obtain video imagery around each of the grid points. If bottom material is moving because of water action, this will become apparent by viewing the grid points at regular intervals. This will assist in isolating what changes are being caused by subsidence.

A possible application for a submersible is to utilize it as a survey vessel and run a regular grid pattern over the area of influence. Utilizing a conventional acoustic navigation system to position the submersible relative to the surface vessel and another acoustic system to collect the information from the submersible to each of the grid points, three dimensional (X, Y, Z) coordinates can be determined.

This system has an advantage over the surface positioning system because the submersible would be directly over each of the points which would upgrade the quality of the Z component. This may also have an indirect positive effect on the quality of the X, Y values.

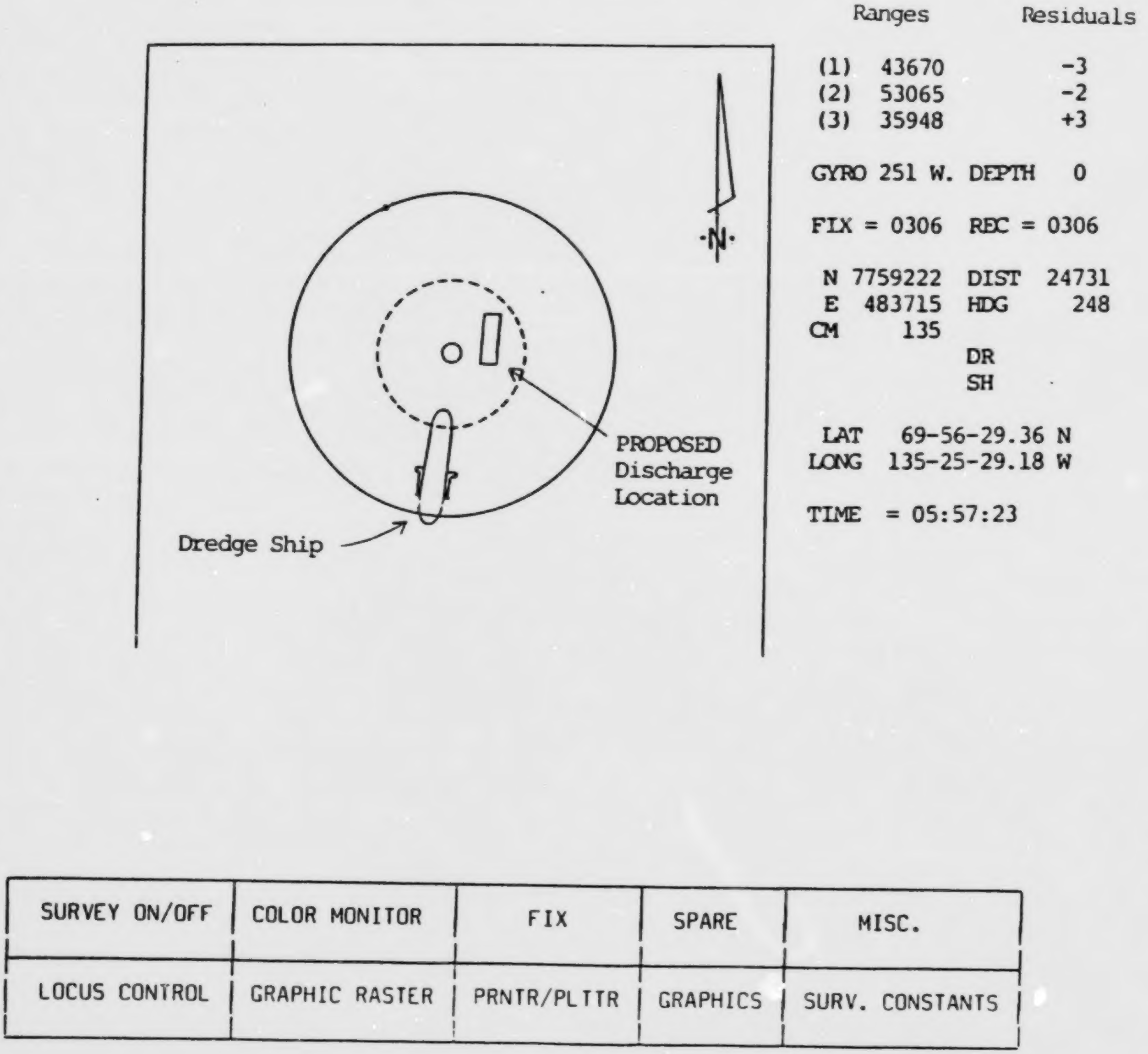
The disadvantages of the system are that more hardware and software are required. More measurements are needed running from the shore to the surface vessel for the submersible to the grid points. This will tend to degrade the accuracy. Because of these additional steps required to determine the position of the points and the apparent lack of any substantial upgrade in accuracy, this alternative does not appear to be feasible.

Graphics.

In any navigation or surveying project, it is important to have a clear and concise picture of the project area and the different components involved, including the survey vessel and the different grid or measurement points.

Previous experience has shown that high quality colour graphics play a key role in the success of survey programs. They simplify the problem of knowing where you are precisely and where you want to go and have been extremely well accepted by various clients. Because high quality colour graphics eases some of the navigation problems, it is a definite asset in trying to derive the most accurate results as possible.

The following are samples of the graphics that have been developed as a result of user needs. These include the dredging of and placement of materials required for island construction (Figures 6-30 and 6-31) and the precise placement of large caisson structures (Figures 6-32, 6-33 and 6-34).

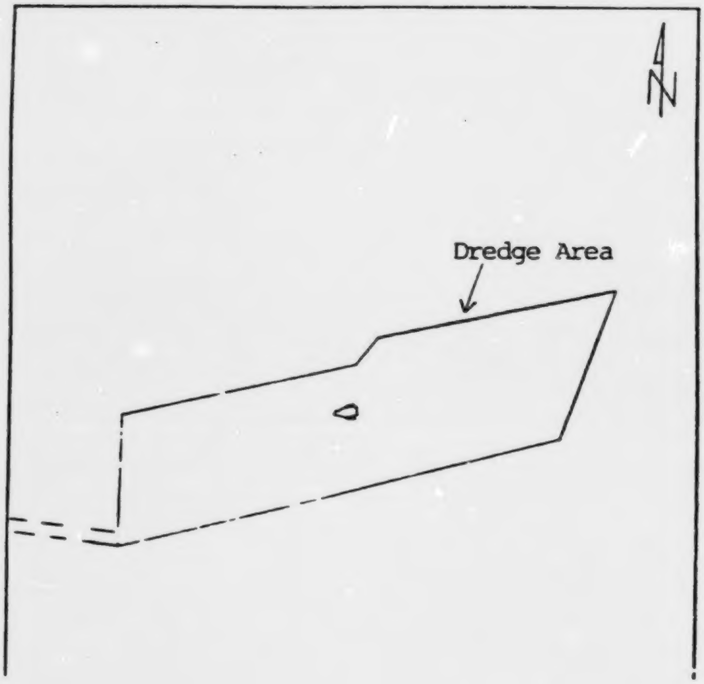

N
PROPOSED
Discharge
Location
Dredge Ship

```
    Ranges        Residuals

(1)  43670            -3
(2)  53065            -2
(3)  35948            +3

GYRO 251 W.  DEPTH   0

FIX = 0306   REC = 0306

 N 7759222   DIST  24731
 E  483715   HDG     248
CM     135
             DR
             SH

 LAT   69-56-29.36 N
LONG  135-25-29.18 W

TIME  = 05:57:23
```

SURVEY ON/OFF	COLOR MONITOR	FIX	SPARE	MISC.
LOCUS CONTROL	GRAPHIC RASTER	PRNTR/PLTTR	GRAPHICS	SURV. CONSTANTS

Graphical Output of Dredge Ship Discharge Location

Figure 6-30



```
    Ranges        Residuals

(1)  43670           -3
(2)  53065           -2
(3)  35948           +3

GYRO 251 W. DEPTH   0

FIX = 0306  REC = 0306

 N 7759222  DIST  24731
 E  483715  HDG     248
CM     135
            DR
            SH

 LAT   69-56-29.36 N
LONG  135-25-29.18 W

TIME  = 05:57:23
```

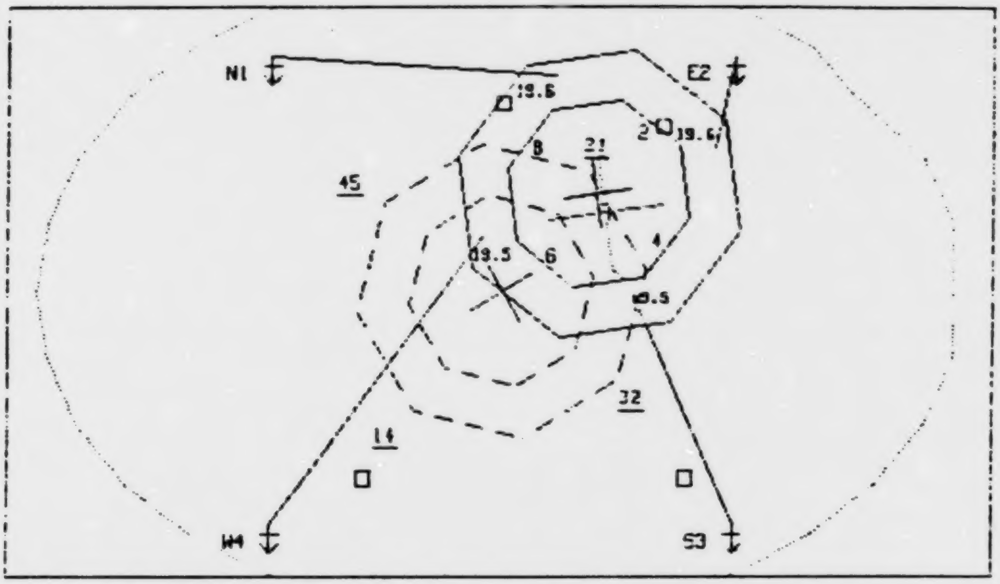
SURVEY ON/OFF	COLOR MONITOR	FIX	SPARE	MISC.
LOCUS CONTROL	GRAPHIC RASTER	PRNTR/PLTTR	GRAPHICS	SURV. CONSTANTS

Sample Output Produced During Dredge Operations

Figure 6-31

A Simulation of the Caisson Moving Toward Target on the Berm

TIME : 09:53:09 NOV 18 1982


N1
E2
19.6
19.6
2
21
8
45
19.5
6
4
19.5
32
14
W4
S3

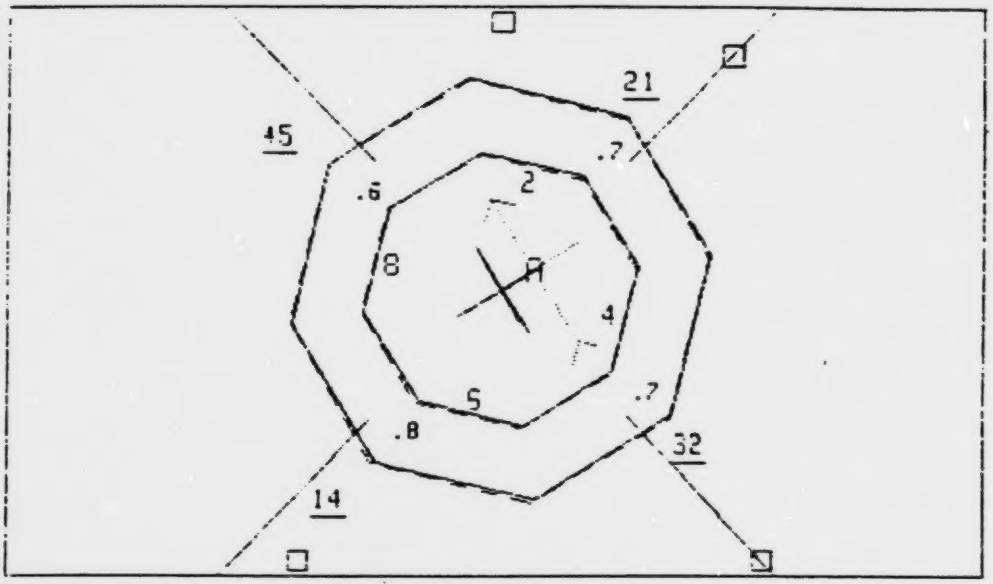
```
CUR: N=7754042 E=494042  (S)   SCALE : ONE TO  2000
TGT: N-7754000 E-494000  VECT. TO TARGET:  59 AT 225
RESID :  MOB 1 :  R1=   70.7  R2=   29.0  R3=   38.0
RESID :  MOB 2 :  R1=   30.3  R2=   18.5  R3=   72.7
```

FOR DEMONSTRATION PURPOSES ONLY

Figure 6-32

Expanded Scale .. Caisson on Target over the berm

TIME : 10:01:40 NOV 18 1982



```
CUR: N=7754001 E=494001  (S)   SCALE : ONE TO  1389
TGT: N-7754000 E-494000  VECT. TO TARGET:   1 AT 225
RESID :  MOB 1 :  R1=   44.5  R2=   31.2  R3=   45.6
RESID :  MOB 2 :  R1=     .6  R2=    1.3  R3=   31.7
```

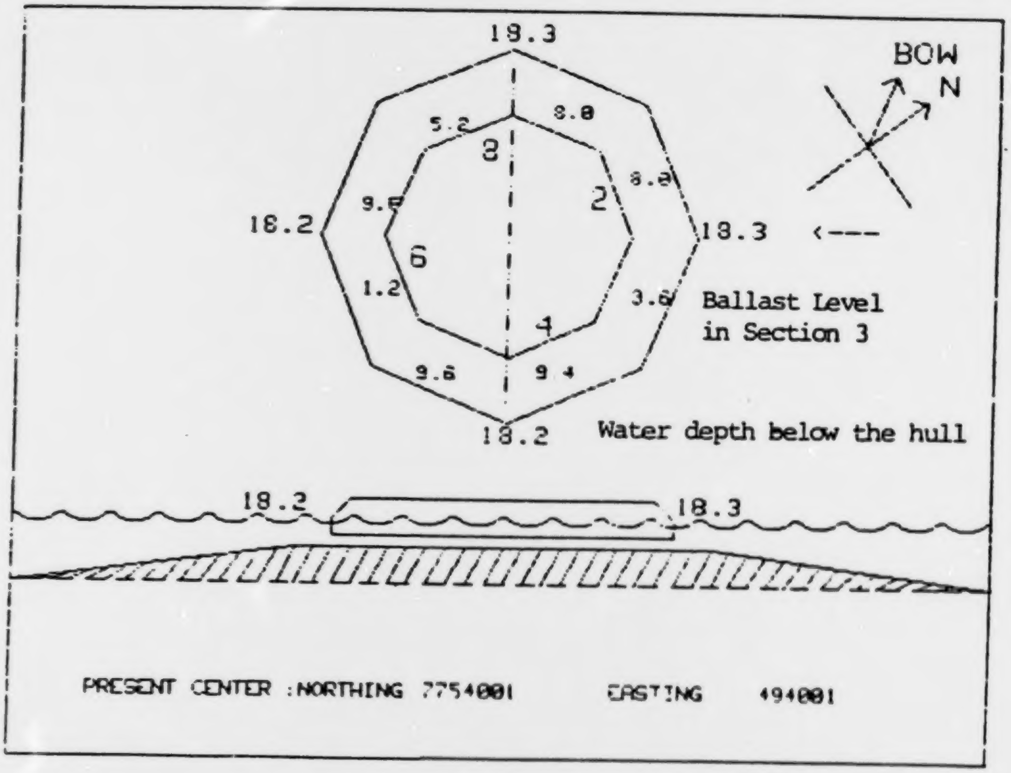
FOR DEMONSTRATION PURPOSES ONLY

Figure 6-33

Typical Output of Data From the Caisson Ballasting System

Plan View and Profile View

TIME : 10:04:22 NOV 18 1982


18.3
BOW
N
5.2
8.8
8
8.8
2
9.8
18.2
18.3
<---
6
1.2
3.6
Ballast Level in Section 3
4
9.6
9.4
18.2
Water depth below the hull
18.2
18.3

PRESENT CENTER :NORTHING 7754001 EASTING 494001

FOR DEMONSTRATION PURPOSES ONLY

Figure 6-34

7.0 MARINE APPLICATION

7.1 Introduction

Marine application of instrumentation available from reputable manufacturers with proven instruments will provide seafloor subsidence reference data. Modifications to field proven strain meters, tilt transducers, and electronic data logging systems will make practical installation possible for long term operation within the marine environment.

Instruments purchased for seafloor installation must be pressure tested at pressures in excess of those expected to guarantee quality of every component. Seafloor installation will require diver placement of all instruments. Installation procedures must be planned to simplify functions a diver can perform quickly to minimize cost and potential weather delays.

7.2 Horizontal Movement

Strain meters are used to monitor the change in distance between two points in a soil or rock mass. The strain meter is made up of a telescoping tubular section, usually PVC or stainless steel pipe sections, fixed to reference flanges. The flanges are set a specified distance apart called the gauge length. Recommended gauge lengths of 2 meters to 8 meters are most practical for land installations because of the flexibility of the telescoping pipe section of the unit. The measuring transducer is fixed to one flange and the moving part of the transducer is attached to the opposite flange by a stiff rod run through the pipe so that any change in the gauge length causes a change in transducer output signal.

The Sinco model 51701 strain meter (Appendix 7-1) is a field proven unit of the type described above. Other manufacturers offer similar strain meters but all such units are built to bury in soil fill installations such as earth dams and embankments.

Modifications will be specified after intial hydrostatic testing of the transducer element and telescoping parts of the strain meter. These changes in specification can be used to negotiate manufacturing changes for subsea units, or standard units can be purchased and modified by responsible project personnel. In either case, quality control must be done by project personnel before installation.

Purchase and testing of the representative device selected should be part of the final design phase of project planning. Transducers utilized in remote reading strain meters are the linear potentiometer type with a 15 cm long resistive element fixed to the transducer housing and a wiper element moved by the change in gauge length.

Signal conditioning the linear potentiometer for computer controlled data logging is done by applying a regulated DC voltage to the transducer of proper magnitude to scale the output signal to the data logger. Expensive amplifiers are usually unnecessary, which reduces cost and increases reliability.

Another transducer which can be used for remote sensing strain meters is the linear variable differential transformer (LVDT). The LVDT is an AC voltage excited, moving core transformer. Integrated circuits are mounted inside the transducer case to allow a DC excitation voltage and convert the output voltage to a DC signal for data logging. Scaling is accomplished by adjustment of the magnitude of the excitation voltage. The LVDT can be purchased for subsea application to pressures in excess of 100 meters of water to eliminate the necessity of a sealed transducer mounting on the strain meter.

Installation of a strain meter requires careful assembly of the unit and adjustment of the gauge length. With the unit set and locked, the transducer must be adjusted for initial setting to accomodate tensile, compressieve, or both directions of strain. After final adjustments, the unit is lowered into place and the end flanges are fixed, then the lock is removed to allow transducer change with flange movement. In a seafloor application these details will require diver interaction and coordination of instrume crew, vessel, and diver.

Electrical cabling must connect each strain meter to a data logging station for excitation of the transducer and recording output signals. The cable length needed on each strain meter must be planned before the unit is built so that cables are one continuous piece from transducer to data logger.

Seafloor installation of strain meters may dictate using short gauge length strain meters in series, end to end, in place of long, unwieldy units.

Horizontal seafloor movement can be measured using multi-position borehole extensometers (Appendix 7-1) installed in a trench in the seafloor. The measurement mechanism and transducer are similar to the strain meter. In this case, up to eight different gauge length units are installed from a common reference point. Changes in gauge length can be taken from each of the anchored rods running parallel in a common trench.

Installation of these multiple rod devices is considered more difficult for a diver and may not be practical.

7.3 Vertical Movement

Vertical movement of the seafloor during development of the subsidence trough is estimated to be 0.4 meter to 1.0 meter maximum at the center line of the trough. A vertical profile of the trough can be calculated from tilt measurements taken at several points on a transverse line across the trough.

Tiltmeters utilize a sensitive servo controlled force balance measuring circuit. A small mass is attached to a moving coil to generate an error signal as the mass moves under force of gravity. The internal servo amplifier generates an output to minimize the error signal by keeping the mass at zero position. The output of the servo amplifier is scaled as output signal proportional to twice the sine of the angle of the base from the horizontal. Standard range is ± 30 degrees with a resolution of ± 10 arc seconds. High sensitivity tiltmeters are available with ± 11 degree range and 2 arc second resolution. Single or biaxial tiltmeters are available if tilt direction cannot be predicted or orientation of the unit is a problem.

Mounting plates are normally purchased with the tiltmeter and grouted or epoxied in place. The seafloor application will require design of a mount compatible with diver placement. The Sinco model 50322 tiltometer (Appendix 7-1) case is hermetically sealed and will not require a specially built case for shallow water application, but the standard electrical connector cannot be used in subsea applications. The cable end could be terminated through an "O" ring sealed cable gland at the instrument case to eliminate the expense of a subsea cable connector.

Tiltmeter measurements must be referenced to bedrock movement to avoid unrelated sediment movement. Locations to be studied with more than 0.5 meters of soil sediment over bedrock may require drilling a mount into the bedrock. A tiltmeter mount can be fabricated to grout into a drilled hole.

For locations with deeper soil sediment, the in-place inclinometer will be easier to install in a hole drilled through the sediment into bedrock. Appendix 7-1 showing the Sinco model 50432 in-place inclinometer illustrates a typical installation of this tool. The measuring principle and sensitivity is the same as the tiltmeter but built for down hole mounting in grooved casing placed in a borehole. These inclinometers are built for significant hydrostatic pressure and would require no modification for use on the seafloor.

In-place inclinometer measurements from the sediment surface and founded in bedrock will provide information concerning sediment motion as the subsidence trough develops.

Pressure measurement is another valid method of measuring vertical subsidence of the seafloor by selecting a pressure transducer of minimum range to withstand the hydrostatic pressure and specifying a 0.01 percent accurate device with adequate resolution. Setra Systems, Inc. manufacture a high quality pressure transducer, Appendix 7-1, which could be adapted to the subsidence application. Design of a protective case and detailed testing must be done to establish final accuracy and resolution based on water depth, temperature change, seastate, and tidal effects on seafloor pressure.

Deployment of pressure transducers can be accomplished with the same diver interaction as the tiltmeter. Pressure change data is a more direct measurement of subsidence than tilt data provided accurate corrections are made for tide and seastate.

7.4 Automatic Data Acquisition System (ADAS)

Figure 7-1 represents a typical seafloor instrument cluster based upon a panel width of 120 meters, coal seam depth of 190 meters, and pillar width of 60 meters. The figure is scaled to indicate distances between measurement stations on the seafloor. Figure 7-2 represents a typical measurement station shown on Figure 7-1.

Assuming each measurement station includes nine strain meter measurements, represented by the dashed lines connecting positions 1 through 6, and two tiltmeter measurements at position 4 and 6, the station has 11 transducers. The instrument cluster would have a total of 88 transducers requiring transducer signal conditioning and data recording. There will be additional information needed relative to tide change, temperature and perhaps redundant measurements of critical locations to bring total channel capacity of the ADAS to about 100. The ADAS location is shown on Figure 7-1.

The ADAS must be located as close as possible to the individual measurement transducers for increased accuracy. A micro processor based data acquisition system designed to signal condition transducers and log data from each measurement station can be located in close proximity to the station

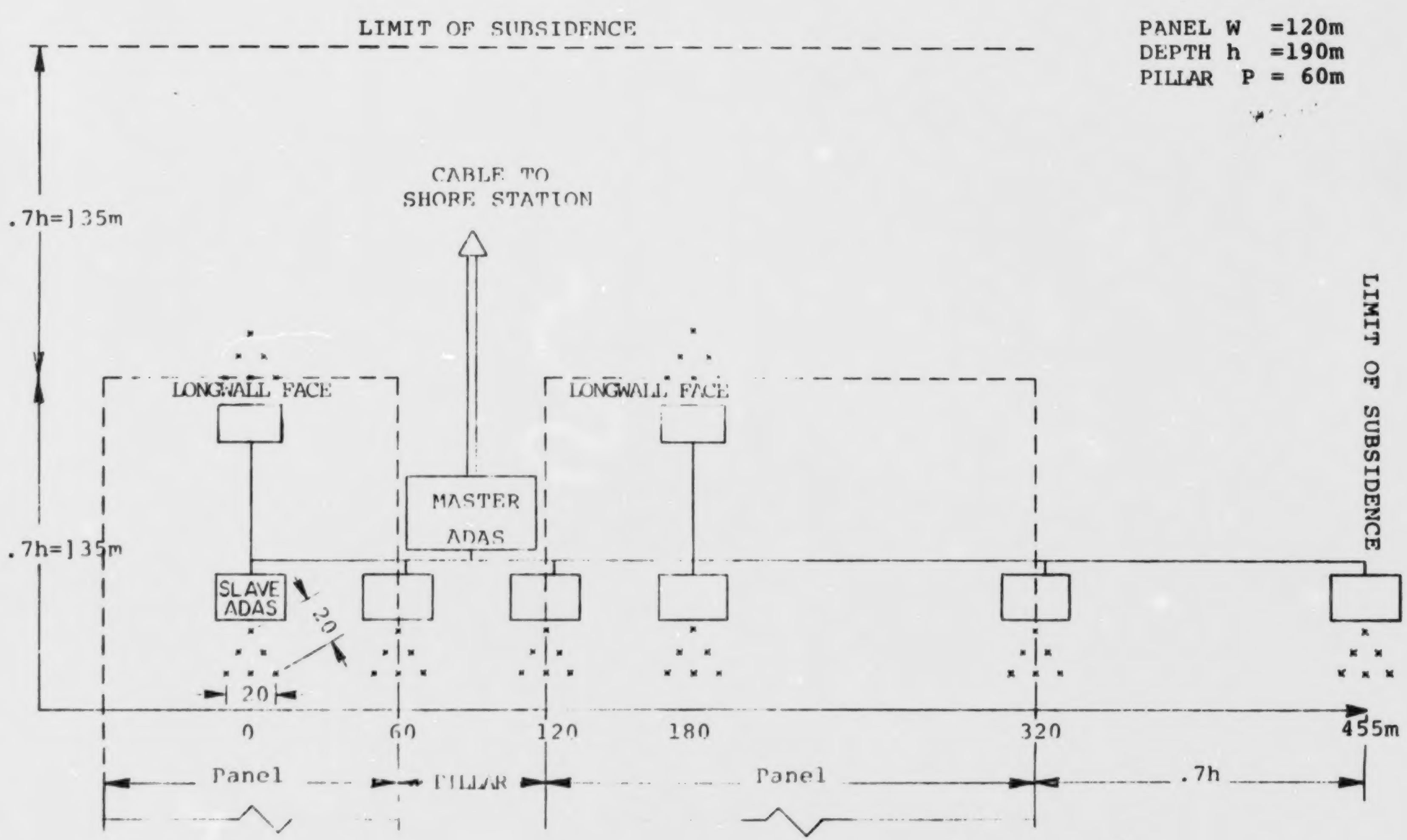

LIMIT OF SUBSIDENCE
PANEL W =120m
DEPTH h =190m
PILLAR P = 60m
.7h=135m
CABLE TO SHORE STATION
LONGWALL FACE
LONGWALL FACE
MASTER ADAS
LIMIT OF SUBSIDENCE
.7h=135m
SLAVE ADAS
20
20
0
60
120
180
320
455m
Panel
PILLAR
Panel
.7h

FIGURE 7-1: SEAFLOOR INSTRUMENT CLUSTER

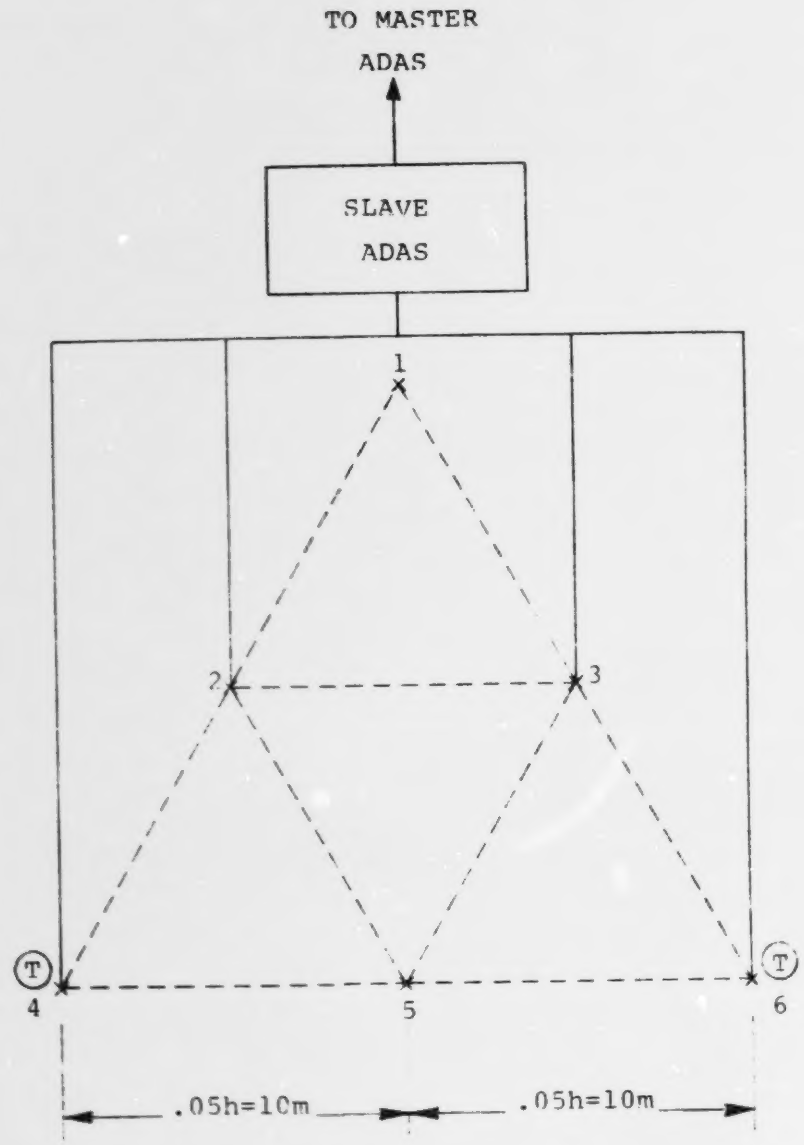

TO MASTER ADAS
SLAVE ADAS
1
2
3
T
T
4
5
6
.05h=10m
.05h=10m

FIGURE 7-2: MEASUREMENT STATION

to minimize individual transducer cable lengths and total cost of cable purchase and installation.

The slave units are connected to a single master ADAS by one cable from each slave. A single cable from the master ADAS to a shore station will allow control via telephone or radio to initiate transfer of data from memory at the master ADAS to data storage and processing at shore offices.

The shore cable can supply low current power to the master station to keep a battery power supply charged for the complete system. A properly sized battery supply would allow the entire system to continue operation during an extended service period in case the shore cable fails from storm or other damage.

If the project economics do not allow the master ADAS and shore cable, each of the slave ADAS stations can be battery powered and serviced from a vessel to collect data and change batteries on a monthly basis.

Individual ADAS units will be mounted in sealed containers designed to withstand the hydrostatic pressure of the deepest planned application. All of the units, cabling and most measurement devices will be retrievable and reusable at future locations. Containers for ADAS units must be designed with future changes possible by a modular concept or expansion space provided.

Expensive cables and connectors must be installed with retrieval in mind in case of necessary service as well as future applications.

Vessel service of ADAS units can be done by acousticly actuated, recallable buoys attached to each unit. The buoy is attached to a soft line to allow the vessel to lift the ADAS package to the surface for service. Cables must be strain relieved at the unit to withstand retrieval and deployment.

Block diagrams of master and slave ADAS units are shown on Figures 7-3 and 7-4. These general block diagrams are the major components needed in this application. There are a number of manufacturers with complete lines of integrated circuit components which serve the functions indicated. Companies like Hewlett-Packard, Intel and Analog Devices (Appendix 7-1) sell such components in both commercial and military grade for high reliability.

Power supply, cabling, and packaging must be done by project oriented designers in order to coordinate all aspects of deployment and service.

Computer software can be done under contract or internally but internally developed software is much more flexible to changes in project objectives which always develop from early field experience. The micro computer in each ADAS unit will carry a preprogrammed instruction set to be executed on a clock command or an external signal. The instruction set can be changed as necessary provided project personnel have developed the software. Changes in software developed under outside contract usually require the service of the original contractor making changes more difficult.

Static computer memory is indicated on the block diagram to take advantage of this latest development which retains data when power is lost.

7.5 Vessel Operated Profiling

Subsidence trough profile could be surveyed using a Sinco horizontal digitilt tool operated from a vessel with diver assistance (Appendix 7-1).

If the instrument cluster location water depth and seafloor conditions allow installation of the grooved tubing during instrument installation, a standard horizontal digitilt device can be used to profile the tubing. A diver on the seafloor can install the probe in the tubing with the cable connected to recording equipment on the vessel. The diver

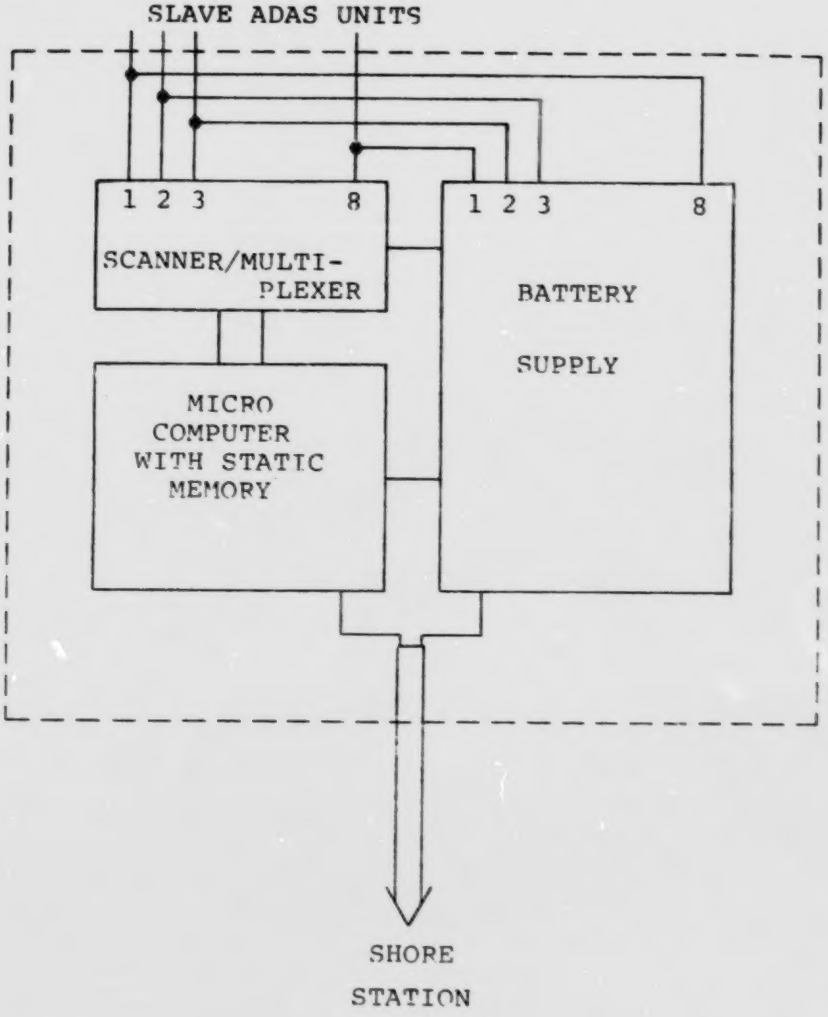

SLAVE ADAS UNITS
1 2 3 8
SCANNER/MULTI-PLEXER
1 2 3 8
BATTERY SUPPLY
MICRO COMPUTER WITH STATIC MEMORY
SHORE STATION

FIGURE 7-3: MASTER ADAS UNIT

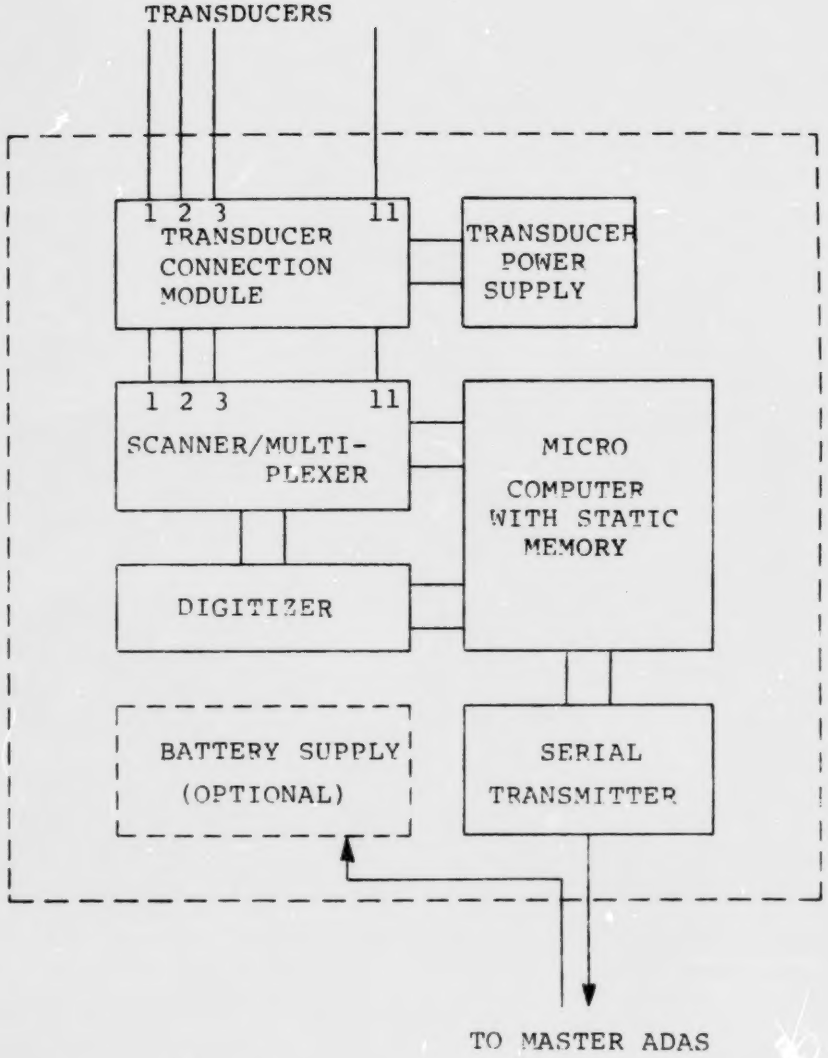

TRANSDUCERS
1 2 3 11
TRANSDUCER CONNECTION MODULE
TRANSDUCER POWER SUPPLY
1 2 3 11
SCANNER/MULTI-PLEXER
MICRO COMPUTER WITH STATIC MEMORY
DIGITIZER
BATTERY SUPPLY (OPTIONAL)
SERIAL TRANSMITTER
TO MASTER ADAS

FIGURE 7-4: SLAVE ADAS UNIT

moves the probe to each location as measured on the probe cable and stops momentarily while the tilt is recorded. The operation continues end to end of the profile tube and is repeated for verification. Simultaneous plotting of the logged profile data provides an immediate check of data.

Profiles generated by this procedure can provide as many data points as are necessary to develop a detailed profile or as few as needed to follow changes. The operation is sea state dependent and may not be practical during winter weather.

A gyroscopic multishot logging tool can be used in a pipe layed much like the grooved tubing for the horizontal digitilt if a tool with sufficient sensitivity is available. Such a device is shown on the Humphry, Inc. (Appendics 7-1). New directional logging tools are under continual development for oil field logging. These tools would require no development for use in the marine environment.

Measuring devices and data recording equipment described in this section are all existing, proven equipment. Application to the marine environment must be done using experienced personnel. Data gathered using these techniques will become a reference for subsea mine subsidence measurements.

8. RECOMMENDED MONITORING SYSTEMS

8.1 Introduction

The previous sections of this report presented detailed information concerning the coalfield, geology, mining operations, site conditions as well as discussion on the various parameters that are required to be measured for a submarine monitoring program. A variety of instruments were discussed which are currently used for land based subsidence monitoring programs as well as marine surveying techniques that will be required in support of instrument deployment and which also may find application for the proposed submarine subsidence monitoring program.

The investigation has not revealed any documented prior attempts to conduct subsidence monitoring within the marine environment. It has, however, revealed the existance of equipment and systems which have been used for somewhat related work which may, with adaptation and development, find application to the proposed work. This section of the report will identify and recommend such equipment and systems, suggest areas for development and modification, present a proposed monitoring scheme and preliminary cost estimates.

8.2 Program objectives and Site Selection

It is recognized that the overall objectives of the monitoring program is two fold. In the first instance, there is no substantial record of subsidence movements in Cape Breton with which to compare to other coal producing areas of the world. It is therefore not possible to determine if the subsidence prediction models, which have been developed for use elsewhere, may be applied to the Sydney coalfield. Secondly, having used a specific subsidence model and designed mining operations for a specific tensile strain at the seafloor (i.e. 8.5 mm/m) it is not possible to verify the actual strains induced by the mining. In the final analysis, it is not possible to assess the efficiency of the mine design nor to assess the potential hazard of water in rush.

Clearly, to meet the foregoing objective and to produce meaningful data, a submarine subsidence monitoring program need necessarily be broad in scope, be long term and monitor numerous walls under various operating parameters. Any systems proposed to achieve this objective must also be compatible with the project needs over the range of variations. It is therefore necessary to certify all components of the system to ensure the application, range of operation, life, integrity and interrelationship with other components of the systems .

It is felt that this may be best attained through field trials of a limited nature in areas where the magnitude of movement may be largest and operating conditions least severe. Field trials will also afford the opportunity to evaluate and compare one monitoring system against another.

With the foregoing in mind, it is suggested that initial trials and monitoring programs be sited either at the Prince Mine or at the new Lingan Phelan. The Lingan Phelan site offers two additional advantages over the Prince Mine site:

- Long wall operations will be nearer the shoreline
- Opportunity exists to correlate seafloor movements with strata movements determined from within the existing mine.

Either site is expected to exhibit high levels of maximum subsidence and maximum tensile strain. Either site is reasonably remote from shipping channels and fishing areas.

8.3 Design Criteria

Design criteria for the subsidence monitoring program were developed within Section 4.4 of this report and are restated as follows:

Monitoring Site

- should cover full extent of movement from at least two adjacent panels in the same seam

- seabed area should be free of sediment problems and unstable ground conditions such as sediment instability and drift which could affect stations

- relatively large amounts of subsidence are required for early testing of seabed monitoring systems

- must be correlated to underground survey to appropriate accuracy.

Layout of Stations

- should include reference stations or monuments on stable ground away from mining

- the relative position to underground workings is crucial and should extend from stable ground over the panel(s) in both longitudinal and transverse directions

- should include additional stations in 45° lines over start/stop positions of panel plus extra stations in zones of tensile strain

- should adopt triangle chain network especially in zones of tensile strain

- should be capable of detecting concentrations of ground movement (e.g. surface cracking, where possible).

Design of Stations

- all stations should be permanently fixed to rockhead (solid rock) to avoid anomalous movement

- all stations should be close to the rockhead surface (to avoid misleading data and to avoid exposure to damage)

- all stations must enable precisely the same point to be measured on each occasion.

Spacing of Stations

- preferred spacing is 0.05 x depth from seam to seabed

- maximum spacing is 0.1 x depth from seam to seabed.

Observations and Accuracy

- station co-ordinates (x,y,z) should be measured as precisely as possible (e.g. ± 1 mm)

- distance between stations should be measured to within a maximum of ± 10 mm or to better than 1 in 10,000 whichever is the smaller

- acceptable closure errors in land based levelling traverses are 1 in 5,000

- should include crack detection and mapping and theodolite angle traverses.

Observation Frequency

- at least two surveys of station layout before mining commences (for calibration of instrumentation and to ensure original positions are known)

- periodic station layout surveys during mining, preferably at intervals of panel advance = 1/20 x depth, 1/10 x depth maximum

- supplementary layout surveys during the passage of the panel beneath the stations to ensure transitional tension zone is detected

- ad hoc measurements taken in areas where unusual or concentration of movement is occurring, as required.

Observation Procedures

- scientific measurement procedures must be adopted (to appropriate international standards)

- details of all calibrations of equipment must be kept

- use of standard/approved instrumentation measurement procedures and data recording

- incorporation of cross-checks in data collection, with immediate re-measurement if required accuracy has not been attained.

Observation Data Analysis and Presentation

- details of actual measurement taken in each survey

- calculation of vertical subsidence profiles along observation lines

- derivation of tilt and tilt profiles from vertical subsidence

- calculation of horizontal displacments and profiles

- derivation of differential horizontal displacement strains - both compressive and tensile, strain profiles

- processing of "triangle" strains to determine magnitude and direction of principal strains

- all profiles should be presented showing relationship of panel position (projected to the seabed, normal to the dip of the seam)

- adoption of suitable computerised 3-D graphical presentation.

Instrumentation

- should be robust to all effects of the operating environment

- should be capable of detecting the smallest acceptable change in the variable required

- should cover the full range of variation expected

- should consistently reproduce the measurement to within the required accuracy

- should be reliable in operation
- should provide data in suitable form for subsequent analysis

8.4 Site Evaluation

Potential monitoring sites will have to be evaluated for bottom conditions, rock outcrop areas, sediment thickness, obstructions, etc. Site evaluation could be most efficiently conducted using a high resolution seismic survey combined with a side scan sonar survey and echo sounder.

The prime objective is to identify areas of rock outcrop. If insufficient outcrop area is determined and instruments need be founded in sediments, the character of those sediments will need to be determined through soil borings and sampling.

The location and identification of obstructions and hazards such as wrecks, pipeline, cables, lost fishing gear, etc., may also be important with respect to placement of instruments and targets in subsequent work.

8.5 Recommended Monitoring Systems

The subsidence monitoring program will involve the measurement of vertical and horizontal movements, and the measurement of tilt or change in surface slope at a given point on the seabed. The previous sections have identified the systems used to monitor surface subsidence on land, and the various instruments that may be utilized in a subsea monitoring program.

Vertical Movement (Settlement)

Vertical movements may be determined indirectly by measuring changes in slope between measurement stations or by measuring the surface tilt at a series of stations. Vertical movements may also be measured more directly by monitoring pressure changes at measurement stations.

The layout of measurement stations (linear or clusters of stations) and the extent of redundancy considered necessary will influence the choice of the measurement systems. The recommended measurement systems for the monitoring of vertical movements are as given below.

Station Arrangement	Measurement System
Linear	Pressure transducers and tiltmeters
Cluster	Horizontal in-place inclinometer and tiltmeters, with pressure transducers used to measure settlement between clusters

Development work required to use the instruments on the seabed, that are currently commercially available, relate primarily to ensuring that electrical cable connections are properly sealed for the expected water pressures; the development of protective casings; and in connection with the pressure transducers, to establish the influence of water depth, temperature change, seastate and tidal affects on seafloor pressure. The inclinometers have been developed for underwater use and should not require any further development for use in the marine environment. However, in place inclinometers are commercially available only for installation in vertical boreholes and some modifications may be needed for use in the horizontal position.

Horizontal Movement

Two potential measurement systems have been identified as being suitable for the measurement of horizontal movements. Strain meters have been used extensively in geotechnical applications to monitor movements within earth dams and embankments. Such instruments are available in various gauge lengths and may be adapted for use on the seabed. Testing of the meters under the expected hydrostatic pressures will need to be undertaken and modifications incorporated as found to be necessary.

The second system that appears to be suitable for the measurement of horizontal movements involves the use of acoustic transponders installed at the measurement stations. Such units have been developed for use in the marine environment and should not require any further development for application in water depths in the study area. Testing will be required to establish the accuracy and resolution obtained for the water depths, temperature changes, etc., at the monitoring station(s).

Tilt

The measurement of surface tilt has been considered under "vertical movements", and commercially available tiltmeters may be adapted for use on the seabed. Several tiltmeter models have been used as part of previous land based subsidence monitoring programs and the development work anticipated for marine application, relate primarily to electrical cable connections, and ensuring a watertight protective casing under the expected hydrostatic pressures.

Sub-Sea Systems

The acoustic system discussed in Section 6.5 has merit for mine subsidence monitoring applications. Similar systems have already been deployed underwater for distance measurement. The accuracy of the system is very near that which is required to derive the necessary strain components of the movement.

The acoustic systems may require final tuning prior to use, however, if successful, would enable all measurements to be made using one type of instrument. Such an approach would obviously simplify instrumentation, signal conditioning, data storage and manipulation.

We are advised that this type of equipment is available for lease or for hire under contract which may be an attractive feature for the early stages of the proposed project.

Sea Surface System

Levels of accuracy for this system as described in Section 6.5, are presently below design criteria specification, however, the system may, with development, prove to be a useful tool that could be calibrated with a sea bottom instrumentation system. The potential exists to use this technique to monitor movements and to produce direct sea bottom profiles.

While the mapping system may not be capable of determining minor movements on the edge of the subsidence profile, it probably could detect the movements in the central parts of the profile.

Low capital costs for equipment and the potential for lease or contract arrangements may be considered favourable. Operating charges will necessarily be higher because of ship charter expense for each survey.

Geophysical Methods

The use of geophysical techniques for this application has been researched via communications with various agencies and is discussed in Section 4 and 6 of this report. Early in the investigation it became clear that these techniques held little promise for use to measure the small strata deformations that is required for the proposed project. Our efforts therefore, were to assess and report informed opinion.

In all cases, the low resolution of the various geophysical systems and the inaccuracies in positioning the sensing devices relative to the seafloor and/or the survey vessel rendered the systems unsatisfactory for use in this application. The most promising techniques were considered to be high resolution, shallow seismic which is reported to give a resolution of 10 - 60 cm. Reproducibility would require resurvey along the identical line which would be extremely difficult within the marine environment.

Such a system may have application in giving a before-after graphical representation in areas of gross movement, however, is unlikely to detect small movements as the subsidence occurs.

8.6 Station Layout

The spacing and layout of measurement stations have been discussed in Sections 4, 5 and 7. The most desired spacing based on the National Coal Board experience is 0.05 x depth of coal seam, with a maximum recommended spacing of 0.10 x depth of coal seam below the seabed. It is recommended that a spacing of 0.05 x depth be adopted for the initial monitoring program.

In order to obtain the subsidence profiles measurement stations will be located along the longitudinal centre line of the mine panels, and in a transverse direction at a distance of at least 1.4 x depth of coal seam, behind the planned termination of the panel face. This arrangement will involve the minimum number of stations considered necessary for the monitoring program. The actual layout of the stations along the longitudinal and transverse directions may assume several configurations as has been outlined in Sections 4 and 5.

An arrangement of stations such as that illustrated in Figures 7-1 and 7-2 will provide subsidence data with fewer stations than a linear arrangement such as that shown in Appendix 4-1. The cluster arrangement of stations as shown in Figure 7-2, consists of a series of triangular groups of stations and these will permit the determination of maximum surface strains at each location at various stages of the mine panel advance. The triangular arrangement also makes the orientation of the stations insensitive to the direciton of the mine advance, while a linear station layout would, in order to obtain maximum strains, be sensitive to the direction of the panel advance. For these reasons, it is recommended that the station cluster arrangement be considered for the monitoring program.

8.7 Deployment and Support Systems

Survey Control

Once specific locations have been identified, a shore based survey control system will have to be employed to control the position of the instrumentation. A complete discussion of the survey system required is given in Section 6.

Instrument stations require lateral and angular control to be sited relative to the longwall to be monitored, as well as from one station set up to the other (cluster).

Control of instrument clusters will probably require the use of sea bottom templates with suitable drilling guides and sea bottom T.V. cameras, divers and or submersibles. These templates will have to be designed specifically for the task.

Vessel

The vessel required in support of deployment must feature stability as a prime requisite. Other features are:

4 point anchoring system with suitable winches.
Lifting cranes
Accomodation for technical, drilling and diving crew.

Drill

A suitable drill must be capable of setting up to 15 cm diameter casing to 1 to 2 m for bottom mounted stations. It is indicated that a land based rig will be suitable. The drill must be equipped for marine application and be complete with necessary grout pumps and supplies.

Two 3 man drill crews will be required for 24 hr. operations.

Diving Support

Marine deployment will require 4 divers on a 24 hour basis to attach instrumentation upon pre engineered mounts and to perform limited final field adjustments. A water depth of 25 m has been assumed which will permit noncompression diving of 40 min duration for each marine connection.

If deeper water depths are encountered or if the marine connection is more complicated, a decompression chamber will be required and 2 additional divers. Remote controlled or manned submersibles may also be necessary.

Seafloor Attachments

All seafloor instrument attachments must be selected or designed for rapid installation by divers. Bayonet or clamp type fittings with quick, remote controlled releases are suggested for rapid deployment and recovery. Specific designs will emerge as equipment is further researched or engineered.

Fixing instrumentation mounts to the rock head may require either grouting methods or expansion type anchors. Pre engineered, quick connect hardware will have to be selected or designed for the specific application.

8.8 Environmental Influence on Deployment and Monitoring Programs

Environmental Factors

Weather conditions will likely dictate the schedule of subsidence monitoring projects, with respect to season. Ice conditions offshore will limit the access to and deployment of instrumentation prior to mid-May. With the exception of fog, which limits visibility during the spring season, there are few impediments to near shore operations until fall. Sea state conditions will not be severe for long periods of time. This area is frequently subjected to hurricane force storms during the fall season which could interrupt sea surface operations for days at a time. It would be prudent to limit sea surface monitoring operations to the period May to October which would allow a 25 week operating schedule.

According to criteria established in Section 4, a minimal duration of measurement in the area of Prince Mine and Lingan Phalen Mine should be 39 weeks. If such a duration is mandatory, it could be met by total remote operation of the monitoring systems which should not be affected by weather. Any floating gear may be at risk during later fall and winter seasons.

8.9 Schedule of Observations

The frequency of monitoring is related to depth and rate of advance of the longwall face. Based on the criteria established, operating depth of 200 m and face advance of 28 m per week, observation frequency should be once or twice per week.

The limiting factor for the number of observations with an automated system is the system power requirements and battery life. If the system incorporates a shore based hardwire link, batteries may be regularly recharged, thus enabling unlimited observations at the discretion of the user.

If the system chosen involves manual service by divers, service by surface vessel or shipboard operations, the availability and cost of ship charters and environmental conditions may be the limiting factors on observation frequency.

8.10 Data Storage and Transmission

Various options are available for data handling as discussed in Sections 6 and 7.

If the initial trials are near shore, a hardware link to a shore base could be considered. Interrogation could be on demand by telephone or on a predetermined clock schedule. Maintenance of battery power supply is also a positive feature of the hardwire link.

Real time data may be obtained by direct telemetry from a data buoy equipped with a radio transmitter, monitored by a shore base.

Another option is to store data on magnetic tape or micro chip systems contained within a data buoy and serviced or interrogated from a surface vessel on demand.

8.11 Estimate of Costs

Cost estimates for various elements for subsidence monitoring programs have been summarized in Table 8-1. The details of the estimates are also presented. Cost estimates have been prepared largely by verbal communication with suppliers and service agencies. More comprehensive estimates can only be prepared following a more precise definition of the selected monitoring program.

In the case of the direct monitoring instrumentation, a fairly detailed estimate of equipment and related development costs is presented. Clearly this system represents a sophisticated, custom adaptation of available technology and requires a high degree of planning, engineering, production control and systems testing. Cost estimates reflect the necessary level of engineering effort. These estimates have been prepared using American sources of supply and prices and have been adjusted for Canadian exchange rate by a factor of 1.3. Canadian sources of equivalent equipment may also be available.

TABLE 8-1

SUMMARY OF COSTS

COST ELEMENT		Estimate
Site Evaluation	Sub bottom seismic side scan sonar echo sounder report and maps 2 km x 2 km survey area	$23,000 job
Detail Survey	To position instrument package and control drill vessel	$ 1,500/day
Deployment	Vessel including marine crew fuel, etc.	$ 4,500/day
	Drill Cost	
	Mobilization	$ 3,000 job
	Operations	$ 2,064/day
	Diving Support 4 man crew including equipment	$ 1,300/day
	Decompression chamber	
	Mobilization	$ 1,000 job
	Rental	$ 2,000/week
	6 man crew	$ 1,900/day
Monitoring Program	Sea Surface system	$276,500 lot
	Acoustical system	$790,000 lot
	Direct Monitoring	$826,000 lot

Cost Detail

Site Evaluation

General site evaluation may be accomplished using a shallow sub bottom profile system, combined with a side scan sonar and echosounder. Estimates of costs for one area 2 km x 2 km located to 2 km offshore in 25 m of water are as follows:

1. Vessel Charges 30 to 40' fishing vessel	$500 per day
2. Equipment Charges	500 per day
3. Positioning system tri sponder using 3 shore based and one mobile with operator	750 per day
4. Crew 2 technicians @ $350	700 per day
TOTAL	$2,450 per day

Total time required including mobilization, installation, 2 day survey - 6 days

Subtotal Survey	$18,000
Report and maps scale corrected to give 100% coverage at 200 m time spacing and photo acoustic mosaic to show sea bottom features to 10 cm Estimate	$ 5,000
TOTAL	$23,000 job

Cost Detail (cont'd)

Survey Costs

Initial siting of the proposed monitoring areas will have to be performed using shore based surveying techniques.

Survey costs as stated in Section 6 are estimated at $1,500 per day for equipment and personnel charges.

Vessel Charges

In support of drilling instrument deployment, a vessel or work barge of 50 m length would be acquired equipped as follows:

- 4 point anchoring systems
- suitable anchoring winches
- lifting winches
- moon pool or other suitable drilling platform
- accomodations for up to 15 working crew for 24 hour operations

Estimate of charges including marine crew $4,500/day

Cost Detail (cont'd)

Drill Costs

It is anticipated that the drilling and grouting of drill rods or casing suitable for the marine attachments could be performed with a land based rig such as a Longyear 38. Estimate of costs as follows:

- Mobilization	$3,000
- Rental - 24 hr. operation	1,020/day
- crew 2 x 3 men @ $14.50/hr.	1,044/day
TOTAL Daily Rate	$2,064

Program Estimate

8 clusters at 6 holes per cluster
total 48 holes - rate 4 per day

Mobilization	$ 3,000
Drill Operations 12 days @ $2,064/day	24,768
Consumables	7,500
TOTAL	$35,268

Diving

Water Depth 25 m

4 man crew including all ancillary equipment	$ 1,300/day

Decompression chamber if required

Mobilization	$ 1,000
Rental	2,000/week
6 man diving crew	1,900/day

Crew accomodations on board, all lifting gear on vessel provided by others

Cost Detail (cont'd)

Sea Surface Systems

Section 6.4 presents a mapping technique which incorporates radio positioning systems, echosounding and heave compensation followed by the generation of a computer produced bathymetric charts. At the present stage of development, the system falls below the level of accuracy required by the task.

It is possible that with further equipment development, and the use of targets, the system may be improved in accuracy. The prime feature of this system is the speed with which the survey may be conducted and the fact that the entire equipment package is ship mounted.

The option for lease arrangments will permit relatively low cost trials to be conducted. Capital costs, and lease charges are repeated following:

Equipment	Capital Cost
Radio Positioning System	$80,000.00
Echo Sounder	41,000.00
Heave Compensator	50,000.00
Computer, Printer, interfaces	20,000.00
Plotter	8,500.00
Temperature, pressure, salinity probes	10,000.00
Tide Gauges (two)	62,000.00
Telemetry Hardware	50,000.00
Total Cost	$276,500.00

Acoustic Positioning System

An acoustic positioning system applied to mine subsidence monitoring is presented in Section 6.4 to include three dimensional definition of monitoring points using accoustical methods and telemetry. As in the previous case, accuracy of the measurement is less than design criteria specifies. However, there may be potential for enhancement.

Capital Cost - Acoustic Positioning System

Item	Cost
Sea Surface System	$176,000.00
Acoustic Receiver and transducer	50,000.00
Bottom-mounted transponders (48 stations at 8625 per station)	414,000.00
Telemetry and Recording System	100,000.00
Post Processing System	50,000.00
Total Cost	$790,000.00

Contract Leasing Costs

	Per Month
Sea Surface	$17,600
Data Collection	40,000
Post Processing	5,000
Total Cost	$62,600

Cost Detail (cont'd)

DIRECT MONITORING INSTRUMENTATION
ESTIMATE OF COSTS

Component Item	Unit Price US Dollars	Quantity	System Total Cost Dollars CDN
1. Slave ADAS - Micro MAC 4000, 12 channels with 13 Bit A-D	2,500		
- Custom design and fabrication 16" diameter container with necessary power supply, connectors, P-C boards and acoustic recallable bouy	10,000		
Subtotal	12,500	8	130,400
2. Master ADAS - Analogic MACSYM 150 computer	6,665		
- Dual Floppy Disc	900		
- Monitor	325		
- 512K byte ram with error correction	2,570		
- External communication ports	3,300		
- Software	2,500		
	16,300		
Master Container - 18 in. ID aluminum pipe section with O-Ring end caps. Internal PC board mounts subsea cable connectors mounted in end caps. Hard anodizing finish custom design fabrication & test	12,100		
Subtotal	28,400	1	36,900
3. ADAS Slave and Master software selection testing & debugging	12,800	1	16,600
4. ADAS Battery & power package including container, charging circuit inverters	5,850	1	7,600

DIRECT MONITORING INSTRUMENTATION
ESTIMATE OF COSTS (Continued)

Component Item	Unit Price US Dollars	Quantity	System Total Cost Dollars CDN
5. Tiltmeters e.g. SINCO Model 50322 including hydrostatic case, seafloor mount, calibration test	3,420	16	70,400
6. Strain meter: SINCO Model 51701 10 meter gauge length, 6 in. double sensor transducers, hardware and anchors, 20 meter cable. (Price based upon 72 units)	1,135	72	106,200
7. Subsea cable for master ADAS to slave ADAS connections. Average 128M per slave (price based on 1000 M order) $3.44/m x 1050 m	3,612		4,700
8. Master ADAS to shore cable Twisted shielded pair No. 20 Twisted Pair No. 16 Polyurethane jacket Assume 1000 m continuous Lengths over 1500 ft at 1.28/ft. Lengths under 1500 ft at 1.05/ft.	4,200		5,500
9. Horizontal digitilt system to operate with a diver and record on vessel			
A) Sinco Model 50329 horizontal digitilt	5,057		
Control cable 500 meter at 20.50/m	10,250		
Cable Reel	3,500		
Dead end pulley assembly and hardware	750		
Digitilt RPP indicator - recorder	12,500		
	32,057		
B) Slope indicator tubing at 18.00 per meter x 1000 m	18,000		
Subtotal	50,057		65,000

DIRECT MONITORING INSTRUMENTATION
ESTIMATE OF COSTS (Continued)

Component Item		Unit Price US Dollars	Quantity	System Total Cost Dollars CDN
System Engineering Costs				
10. Prelimimary engineering Estimate Project Planning Instrument Specification Final Vendor Selection Interface Definition Software Specification Project Reporting	800 hrs.			48,000
11. Prototype Engineering and Testing (2000 hours) Vendor Liaison - Monitoring Test Plan Test Preparation Test Perform Test Evaluation report Modify instrument as required	2000 hrs.			120,000
12. Production Engineering Vendor Monitoring Quality Assurance Component Testing Final System Test Shipment Preparation Final Report	400 hrs.			24,000
Subtotal				635,300
13. Contingency Because of the uncertainty in this first-time ever project, a 30% contingency is recommended based on the total contract price (hardware and engineering)				190,590
GRAND TOTAL				825,890

NOTE: Above cost estimate based on US suppliers and experience with "similar system" design fabrication and testing.
Exchange rate used Canadian Dollars = 1.3 x US dollars

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AU: Fisekci M.Y. (Mining Research Lab., Calgary, Alberta);
Chrzanowski A.
SO: Workshop on surface subsidence due to underground mining,
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AU: O'Rouke J.E.
SO: Workshop on surface subsidence due to underground mining,
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TI: Subsidence monitoring over western coal mines.
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AU: Allgaier F.K.
SO: Workshop on surface subsidence due to underground mining,
Morgantown, WV, USA, 30 Nov 1981. DE--82020615 CONF-811173-- 156-163
pp (Mar 1982) Peng, S.S.; Harthill, M. (eds.) (In English)

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TI: Subsidence monitoring - case history.
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AU: Conroy P.J. ; Gyarmaty J.H.
SO: Workshop on surface subsidence due to underground mining,
Morgantown, WV, USA, 30 Nov 1981. DE--82020615 CONF-811173-- 148-155
pp (Mar 1982) Peng, S.S.; Harthill, M. (eds.) (In English)

Ref. 31

TI: Measurement and prediction of mine subsidence over room and pillar workings in three dimensions.
In Workshop on surface subsidence due to underground mining.
AU: Choi D.S. ; Dahl H.D.
SO: Workshop on surface subsidence due to underground mining,
Morgantown, WV, USA, 30 Nov 1981. DE--82020615 CONF-811173-- 34-47
pp (Mar 1982) Peng, S.S.; Harthill, M. (eds.) (In English)

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TI: Workshop on surface subsidence due to underground mining.
AU: Peng S.S. ; Harthill M. (eds.)
CS: West Virginia Univ., Morgantown (USA). Dept. of Mining Engineering
SO: Workshop on surface subsidence due to underground mining,
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(Mar 1982) (In English)

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TI: Stress Alert bold additional safety tool
AU: Hughson D.
SO: North. Miner; 68 (33); A26-A27 (Oct 1982) (In English)
CO: NMNRA

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TI: Design and demonstration of subsidence monitoring systems. Final report.
AU: Ranson B.B. ; O'Rourke J.E. ; Rey P.H.
CS: Woodward-Clyde Consultants, San Francisco, CA (USA)
SO: DE--82021321 DOE/ET/12220--T1 282 pp (Sep 1982) (In English)

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TI: Geotechnical study of an ash deposit.
In Challenge of change: sixth international ash-utilization symposium proceedings.
AU: Wood G.L.
SO: 6. international ash utilization symposium Reno, NV, USA, 7 Mar 1982. DE--83000579 DOE/METC--82-52-Vol.2 CONF-820333--Vol.2 349-370 pp (Jul 1982) Halow, J.S.; Covey, J.N. (eds.) (In English)

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CS: Economic Commission for Europe
SO: ECE/COAL--71 New York, NY, USA, United Nations, vp (19 Oct 1982) (In English)

Ref. 37

TI: Avoiding falls of rock, surveying of mines.
In Steinkohlenbergbauverein - Jahresbericht 1980.
SO: Essen, FRG, Steinkohlenbergbauverein, pp 14-19 (1981) (In German)

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TI: Review of underground coal-gasification field experiments at Hoe Creek.
AU: Thorsness C.B. ; Creighton J.R.
CS: Lawrence Livermore National Lab., CA (USA)
SO: American Institute of Chemical Engineers' spring meeting, Anaheim, CA, USA, 8 Jun 1982. DE--82015508 UCRL--87662 CONF-820610--8 42 pp (26 May 1982) (In English)

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TI: Analysis of alternative responses to mining subsidence hazards: current status and future direction.
AU: Rapp D.A. ; Greenwood J.M. ; Goetzinger J. ; Oberhettinger D. ; Stroup C.A.
CS: Los Alamos National Lab., NM (USA)
SO: DE--82009715 LA--9239-MS 63 pp (Feb 1982) (In English)

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TI: Seventh underground coal conversion symposium.
CS: Lawrence Livermore National Lab. CA (USA)
SO: 7. underground coal conversion symposium Fallen Leaf Lake, CA, USA, 8 Sep 1981. DE--82004729 CONF-810923-- 843 pp (1981) (In English)

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TI: A study of the behaviour of overlying strata in longwall mining and its application to strata control.
In Strata mechanics
CS: Chien Ming-Gao
SO: Symp. on strata mechanics, Newcastle-upon-Tyne, UK, 5-7 Apr 1982. Amsterdam, Netherlands, Elsevier Scientific Publishing, pp 13-17 (1982) Developments in geotechnical engineering vol. 32 Farmer, I.W. (ed.) (In English)
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CS: Central Mining Research Station Dhanbad
SO: Dhanbad, India, Central Mining Research Station, 165 pp (nd) (In English)

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TI: Increase in surface mine safety by employing a warning instrument for slope movements
AU: Sternitzke H.
SO: Sicherheit; 28 (2); 28-29 (Mar 1982) (In German)
CO: SICHD

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TI: Subsurface subsidence damage monitoring: seismic tomography and microgravimetry.
AU: Albright J.N. ; Halleck P.M. ; Pearson C. ; Fehler M.
CS: Los Alamos National Lab., NM (USA);Oregon State Univ. Corvallis (USA)
SO: Workshop on surface subsidence due to underground mining, Morgantown, WV, USA, 30 Nov 1981. DE--82010395 LA-UR--82-287 CONF-811173--2 9 pp (1981) (In English)

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TI: Investigations into rheological properties of loess in the Lublin coal basin
AU: Frolik A.
SO: Ochr. Terenow Gorn.; 15 (58); 37-42 (1981) (In Polish)

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TI: Predicting surface subsidence by measuring subsidence of a mined coal seam
AU: Pytlarz T.
SO: Ochr. Terenow Gorn.; 11 (39); 43-45 (1977) (In Polish)

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TI: The Syaleb system for forecasting falls of ground in mines
AU: Barou S.
SO: Ind. Miner., Tech.; (9); 669-677 (Nov 1981) (In French)
CO: INMTD

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TI: Investigation of the effects of weak floor conditions on the stability of coal pillars. Open file report (final) 27 Jun 75-31 Dec 78.
AU: Rockaway J.D. ; Stephenson R.W.
CS: Missouri Univ., Rolla (USA);Bureau of Mines Washington DC (USA)
SO: PB--81-181109 227 pp (15 Jul 1979) (In English)

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TI: Subsidence from deep longwall mining of coal overlain by massive sandstone strata.
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AU: Kapp W.A.
SO: Annual conf. of Australasian Institute of Mining and Metallurgy, Sydney, NSW, Australia, Jul 1981, Parkville, Victoria, Australia, Australasian Institute of Mining and Metallurgy, pp 229-246 (1981) (In English)
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TI: Analysis of the stability of a highwall in an open cut strip coal mine
AU: Cox R.H.T.
SO: CSIRO-DAG-GCM--30 Mount Waverley, Victoria, Australia, Commonwealth Scientific and Industrial Research Organization, Division of Applied Geomechanics, vp (1981) (In English)

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TI: Use of digital techniques for modelling electric resistivity methods applied for solving problems associated with preparing mining areas for building requirements
AU: Brzezanski A. ; Kielt M.
SO: Wiad. Gorn.; 32 (10/11); 260-266 (Oct 1981) (In Polish)
CO: WDGOA

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TI: Rock mechanics design criteria for longwall mining at Angus Place colliery
AU: Schaller S. ; Hebblewhite B.K.
SO: ACIRL-PR--81-3 North Ryde, NSW, Australia, Australian Coal Industry Research Laboratory Ltd., 82 pp (1981) (In English)

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TI: Measurement and calculation of surface effects of mining as a means to prevent damage done by mining
AU: Pflaeging K.
SO: Markscheidewesen; 88 (2); 343-352 (May 1981) (In German)

Ref. 54

TI: Progress in underground mining of coal under the difficult mountainous conditions of Western Canada.
In Tenth world mining congress. Vol. 3. Progress in mining methods under difficult conditions
AU: Fisekci M.Y. ; Grimley A.W.T. ; Cochrane T.S.
SO: 10. world mining congress, Istanbul, Turkey, 17-21 Sep 1979. Ankara, Turkey, Maden Tetkik ve Arama Enstitusu, vol. 3, paper III-10, 24 pp (1979) (In English)

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TI: Proceedings of the second international conference on ground movements and structures
AU: Geddes J.D. (ed.)
SO: 2. int. conf. on ground movements and structures, Cardiff, UK, Apr 1980. London, UK, Pentech Press, 975 pp (1981) (In English)
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TI: Determining displacements of reproduced points during periodic geodetic observations in areas of ground motion occurrence
AU: Szpetkowski S.
SO: Ochr. Terenow Gorn.; 15 (55); 38-43 (1981) (In Polish)

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TI: Activities of Inspectorates of Mines in the field of surface protection from mining damage
AU: Naglik W.
SO: Ochr. Terenow Gorn.; 14 (54); 3-7 (1980) (In Polish)

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TI: Regulation of the hydrologic impacts of underground coal gasification.
In Sixth underground coal-conversion symposium.
AU: Lacy J.C. ; French L.N. ; Grimshaw T.W.
SO: 6. underground coal conversion symposium Afton, OK, USA, 13 Jul 1980. CONF-800716-- V.91-V.100 pp (1980) (In English)

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AU: Grant J.F. ; Haney S.E.
SO: 6. underground coal conversion symposium Afton, OK, USA, 13 Jul 1980. CONF-800716-- V.7-V.12 pp (1980) (In English)

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TI: Ground-water effects of the UCG experiments at the Hoe Creek site in northeastern Wyoming.
AU: Mead S.W. ; Wang F.T. ; Stuermer D.H.
CS: Lawrence Livermore National Lab., CA (USA)
SO: Institute of Gas Research conference Los Angeles, CA, USA, 28 Sep 1981. DE--81023660 UCRL--85468 CONF-810909--2 22 pp (Jun 1981) (In English)

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TI: Burn cavity growth during the Hoe Creek No. 3 underground-coal-gasification experiment.
AU: Hill R.W.
CS: Lawrence Livermore National Lab., CA (USA)
SO: 7. underground coal conversion symposium Fallen Leaf Lake, CA, USA, 8 Sep 1981. DE--81027533 UCRL--85173-R-1 CONF-810923--4(R-1) 26 pp (8 Jun 1981) (In English)

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CS: Lawrence Livermore National Lab., CA (USA)
SO: Institute of Gas Research conference Los Angeles, CA, USA, 28 Sep 1981. UCRL--85173 CONF-810909--1 22 pp (14 Jan 1981) (In English)

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In Sixth underground coal-conversion symposium.
AU: Varisco D.C. ; Wilkerson J.M. ; Follick J.H.
SO: 6. underground coal conversion symposium Afton, OK, USA, 13 Jul 1980. CONF-800716-- II.49-II.58 pp (1980) (In English)

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TI: Proceedings of the fourth congress of the International Society for Rock Mechanics
SO: 4. congress of the International Society for Rock Mechanics, Montreux, Switzerland, 2-8 Sep 1979. Rotterdam, Netherlands, A.A. Balkema, vol. 3, 559 pp (1979) (In English)
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TI: Report from the 6th Danube European Conference on Soil Mechanics and Foundation Engineering
AU: Foerster W. ; Gehrisch M.
SO: Neue Bergbautech.; 11 (5); 304-306 (May 1981) (In German)
CO: NEBBA

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TI: Monitoring mining deformation of the surface by observation of changes in the electrical resistance of the rock mass
AU: Spiewakowski S.
SO: Ochr. Terenow Gorn.; 14 (52); 31-34 (1980) (In Polish)

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TI: Underground excavations at lesser depths: five years' experience in the development and supervision of their stability
AU: Dejean J.F. ; Schwartzmann R.
SO: Publ. Tech. Charbon. Fr.; (1); 1-7 (1981) (In French)
CO: PTCFA

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TI: Ground tilt in relation to subsidence in longwall mining
AU: Whittaker B.W. ; Pasamehmetoglu A.G.
SO: Int. J. Rock Mech. Min. Sci. Geomech. Abstr.; 18 (4); 321-329 (Aug 1981) (In English)
CO: IRMGB

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TI: Demonstration of subsidence monitoring system. Final report.
AU: Conroy P.J. ; Gyarmaty J.H. ; Pearson M.L.
CS: Dames and Moore, Park Ridge, IL (USA)
SO: DE--81023961 DOE/ET/10029--T1 435 pp (Jun 1981) (In English)

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AU: Bauer E.R. ; Chekan G.J.
CS: Pennsylvania Univ., Philadelphia (USA). National Center for Energy Management and Power
SO: BM-TPR--113 11 pp (Mar 1981) (In English)

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AU: O'Rourke J.
CS: Woodward-Clyde Consultants, San Francisco, CA (USA)
SO: DOE/PC/30117--T2 42 pp (1980) (In English)

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TI: Slope failures in surface mines, methods of studying landslides
AU: Flisiak J. ; Korman S. ; Mazurek J.
SO: Gornictwo (Katowice); 1 (1); 71-92 (1977) (In Polish)

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TI: Recent success in the observation and evaluation of displacements and changes in the subsidence area.
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SO: 4. int. symp. on mine surveying (ISM-4) Aachen, FRG, 24-29 Sep 1979. Herne, FRG, Deutscher Markscheider-Verein, e.V., Vol. 4, pp 15-24 (1979) Vosen, H. (ed.) (In German)

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Vol.2
AU: Chwastek J.
SO: 4. int. symp. on mine surveying (ISM-4) Aachen, FRG, 24-29 Sep 1979.
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Vol. 2
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SO: 4. int. symp. on mine surveying (ISM-4) Aachen, FRG, 24-29 Sep 1979.
Herne, FRG Deutscher Markscheider-Verein e.V., Vol.2, pp 169-181
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CS: Woodward-Clyde Consultants San Francisco CA (USA)
SO: DOE/PC/30117--T1 13 pp (20 Feb 1981) (In English)

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In First conference on ground control problems in the Illinois Coal
Basin: proceedings.
AU: Santy W.P. (Dept. of Energy, Carbondale, IL (USA)); Eichfeld W.F.
; McKelvey R.J.
SO: 1. conference on ground control problems in the Illinois coal basin,
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AU: Kettren L.P. ; Johnston K.A.
SO: 1. conference on ground control problems in the Illinois coal basin,
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AU: Peng S.S.
SO: New York, NY, John Wiley and Sons, Inc., 459 pp (1978) (In English)

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AU: Dick R.A. ; Siskind E.
SO: Coal conference and EXPO V Louisville, KY, USA, 23 Oct 1979.
CONF-7910117-- New York, NY, McGraw-Hill, Inc., 13-18 pp (1979)
(In English)

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TI: A study of mine subsidence at two collieries in the Southern Coalfield, New South Wales
AU: Kapp W.A.
SO: Australas. Inst. Min. Metall. Proc.; (276); 1-11 (Dec 1980)
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CO: AMMPA

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TI: Role and aims of mine surveying in environmental protection at the Belchatow brown coal mine.
In Shaping and protecting the natural environment in the Belchatow mining-energy basin (Ksztaltowanie i ochrona srodowiska w Belchatowskim zaglebiu gorniczo-energetycznym)
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SO: Conf. on shaping and protecting the natural environment in the Belchatow mining-energy basin, Belchatow, Poland, 26-27 Sep 1979.
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In Stability in coal mining
AU: Wyllie D.C. ; Munn F.J.
SO: 1. int. symp. on stability in coal mining, Vancouver, British Columbia, Canada, April 1978. San Francisco, California, USA, Miller Freeman Publications, PP 75-94 (1979) Brawner, C.O.; Dorling, I.P.F. (eds.) (In English)
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AU: Singh R.D.
SO: 4. congress of the International Society for Rock Mechanics, Montreux, Switzerland, 2-8 Sep 1979 Rotterdam, Netherlands, A.A. Balkema, vol. 1, pp 731-736 (1979) (In English)
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SO: 4. congress of the International Society for Rock Mechanics, Montreux, Switzerland, 2-8 Sep 1979. Rotterdam, Netherlands, A.A. Balkema, vol. 1, pp 665-670 (1979). (In English)
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AU: Maloszewski J. ; Kuzniak T.
SO: Wiad. Gorn.; 31 (8/9); 244-248 (Aug 1980) (In Polish)
CO: WDGOA

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TI: Geotechnical analysis for longwall design
AU: Conroy P.J.
SO: Coal Min. Process.; 17 (12); 50-54 (Dec 1980) (In English)
CO: CMPRB

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TI: On the applicability of airborne infrared measurement techniques in the exploration of ground subsidence areas
AU: Gebhardt A.
SO: Z. Angew. Geol.; 26 (8); 416-420 (Aug 1980) (In German)
CO: ZANGA

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AU: Nielsen M.N.
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CS: California Univ., Livermore (USA). Lawrence Livermore Lab.
SO: 6. underground coal conversion symposium Afton, OK, USA, 13 Jul 1980. UCRL--83961 CONF-800716--3 12 pp (20 May 1980) (In English)

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SO: Neue Bergbautech.; 10 (3); 183-187 (Mar 1980) (In German)
CO: NEBBA

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TI: Activities of the Association of Mining Engineers and Technicians
AU: Pytlarz T.
SO: Przegl. Gorn.; 36 (3); 153-155 (Mar 1980) (In Polish)
CO: PRGOA

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TI: Evaluation of European empirical methods for subsidence in US coal fields.
AU: Munson D.E. ; Eichfeld W.F.
CS: Sandia National Labs., Albuquerque, NM (USA);Department of Energy Carbondale IL (USA). Carbondale Mining Technology Center
SO: SAND--80-0537 27 pp (Apr 1980) (In English)

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AU: McCabe K.
SO: Conference on coal seam discontinuity Pittsburgh, PA, USA, 3 Nov 1976. CONF-7611121-- Pittsburgh, PA, D'Appolonia Consulting Engineers, 3.1-3.18 pp (1978) Voelker, R.M. (ed.) (In English)

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AU: Mead W. ; Raber E.
CS: California Univ., Livermore (USA). Lawrence Livermore Lab.
SO: 2. DOE environmental control symposium Reston, VA, USA, 17 Mar 1980. UCRL--84075 CONF-800334--2 18 pp (14 Mar 1980) (In English)

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AU: Bilkenroth K.-D. ; Wiesner H.
SO: Neue Bergbautech.; 9 (12); 713-715 (Dec 1979) (In German)
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AU: Gustkiewicz J. ; Klein G.
SO: Int. symp. on field measurements in rock mechanics, Zurich, Switzerland, 4-6 Apr 1977. Rotterdam, Netherlands, A.A. Balkema, Vol 1, pp 123-135 (1977) Kovari, K. (ed.) (In English)

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AU: Wright F.D. ; Howell R.C. ; Dearinger J.A.
CS: Kentucky Univ., Lexington (USA)
SO: FE--9010-T1 288 pp (Apr 1979) (In English)

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AU: National Coal Board, Mining Department

SO : NCB, London (Revised Edition, 1975)

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Part 1: Theory and practices in predicting surface deformation
Part 2: Ground movements and mining drainage

AU: Brauner G

SO : USBM IC8571, 8572. Cat Nos. 128.27:8571 (pt. 1), 128.27:8572 (pt. 2)
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AU: Symposium organised by the British Geotechnical Society, held 30th May -1st June 1973

SO : London, Butterworth (1973), ISBN 0408 70514 0

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TI : Geophysical examination of coal deposits

AU: Jackson L. J.

SO : IEA Coal Research, London, Report No. ICTIS/TR 13 (April 1981)

Ref. 105

TI : Methods and Equipment for Measuring Subsidence In Third Symposium on Salt, Vol. 2

AU: Panek L. A.

SO : Third Symposium on Salt, Northern Ohio Geological Society Inc., Cleveland, Ohio, USA, October 1970

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AU: Archibald G. I., Weir A. M.

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AU: Conroy, Dr P J, Gymarty J H

CS : Dames & Moore, 1550 Northwest Highway, Park Ridge, Illinois USA

SO : US Dept of Energy Contract No DE-AC22-80PC 30335(1980-84)

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AU: Fisekci M Y, Chrzanowski A, Das B M, LaRocque G.

SO : 1st Annual US Conference on Ground Control in Mining, University of West Virginia, USA, July 1981.

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AU: Fisekci M Y, Parkes D

SO : 7th International Strata Control Conference, INIEX, Liege, Belgium 20th-24th September 1982.

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AU: Bullock K P.

SO : Mining Magazine, Vol 150, 4, 379-385. (April 1984).

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AU: Tubby J E, Farmer I W.

SO : Mining Engineer, London. Vol 141, 239, pp 87-96 (Aug 1981).

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– Australia	5,49,52,82,90
– South Africa	21,119
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Volume

2

A REVIEW AND EVALUATION OF POTENTIAL DATA COLLECTION METHODS FOR MONITORING SUBSIDENCE OVER LONGWALL WORKINGS IN SUBMARINE COALFIELD

VOLUME II
APPENDICES

DSS FILE NUMBER: 23SQ.23440-3-9031
CONTRACT SERIAL NUMBER: 0SQ83-00290

269 pp

A Review and Evaluation of Potential Data Collection Methods for Monitoring Subsidence Over LongWall Workings in Submarine Coalfield

VOLUME II
APPENDICES

BY

JACQUES, WHITFORD AND ASSOCIATES LIMITED

With

ASSOCIATED MINING CONSULTANTS LTD.
McCLELLAND ENGINEERS INC.
CANADIAN SURVEY CONSULTANTS

Work on this project was conducted under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada

DSS FILE NUMBER: 23SQ.23440-3-9031
DSS CONTRACT SERIAL NUMBER: 0SQ83-00290
CANMET PROJECT NUMBER:
CANMET SCIENTIFIC AUTHORITY: Dr. T.R. C. Aston, P.Eng.

JUL 03 1985
MICROMEDIA

Halifax, Nova Scotia

October, 1984

APPENDIX 1

1-1 Statement of Work

APPENDIX 1-1

STATEMENT OF WORK:

1. Prepare summary descriptions of current subsidence instrumentation systems together with evaluation of their potential for application in undersea monitoring. This summary shall be based on review of relevant literature augmented by correspondence and personal communications with appropriate authorities. Personal visits require prior approval of the Scientific Authority.

   (Note: This contract is not intended to produce a review of subsidence prediction theories and/or models which can be used for underdea workings.)

2. Evaluate current technology which could be used to detect complete undersea subsidence profiles and associated strain profiles. An attempt must be made to consider all possible approaches, but consideration must be given to the limitations imposed by the hostile environment of near shore (less than 10 km) seabed conditions.

3. The contractor shall bear in mind that the report should not definitively pursue any single approach, but identify promising approaches which could with further development, lead to the accurate determination and delineation of subsidence profiles at seafloor or seafloor-bedrock horizons.

4. As part of this review the contractor is expected to identify areas where R&D effort could lead to suitable practical data collection methods and highlight promising developments anticipated in the next five years.

5. This review is not limited to technology developed by or for the mining industry.

6. The final report, summarizing all activity is to be provided to the Scientific Authority by March 31,1984.

7. After submission of and acceptance of the final report, the contractor shall prepare a verbal presentation outlining the problems and successes associated with the work and present this material in a debriefing seminar to CANMET representatives and interested outside parties. The time and location (usually Sydney or Ottawa) of the presentation will be at the discretion of the Scientific Authority.

APPENDIX 3

3-1 Air Temperature 1860 to 1982 Cape Breton Shore

3-2 Wind Speed 1860 to 1982 Cape Breton Shore

3-3 Frequency of Wind Speed by Direction on a Seasonal Basis

3-4 Wind Speed Exceedance 1860 to 1982 on a Seasonal Basis

3-5 Shipping Weather 1860 to 1982 Cape Breton Shore

3-6 Sea Surface Temperature 1860 to 1982 Cape Breton Shore

3-7 Salinity Values Cape Breton Shore

3-8 Combined Wave Height 1860 to 1982 Cape Breton Shore

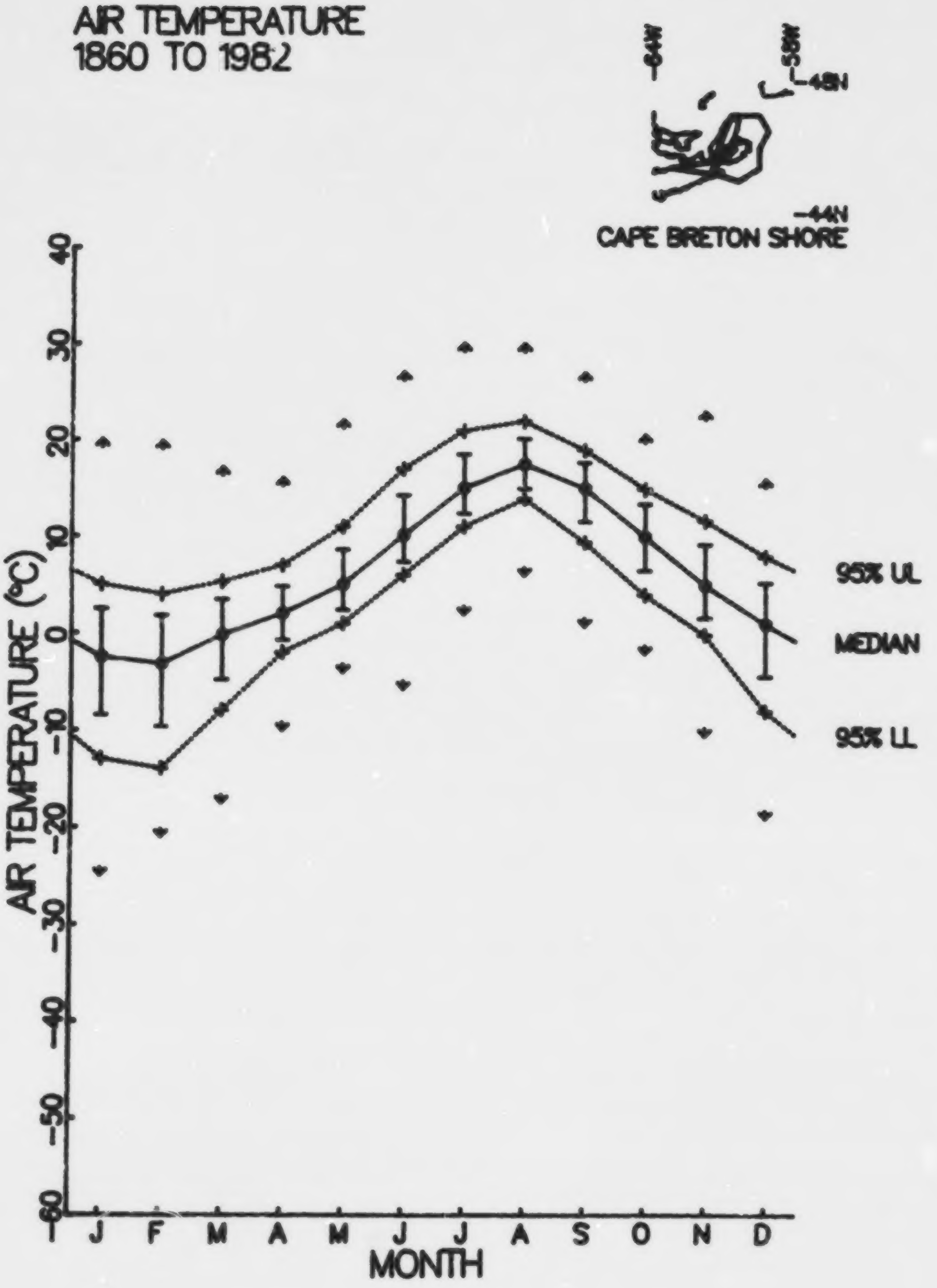
3-9 Frequency of Combined Wave Height by Direction on a Seasonal Basis

3-10 Combined Wave Period Frequencies 1860 to 1982 on a Seasonal Basis

3-11 Combined Wave Height Exceedence 1860 to 1982 on a Seasonal Basis

Appendix 3-1

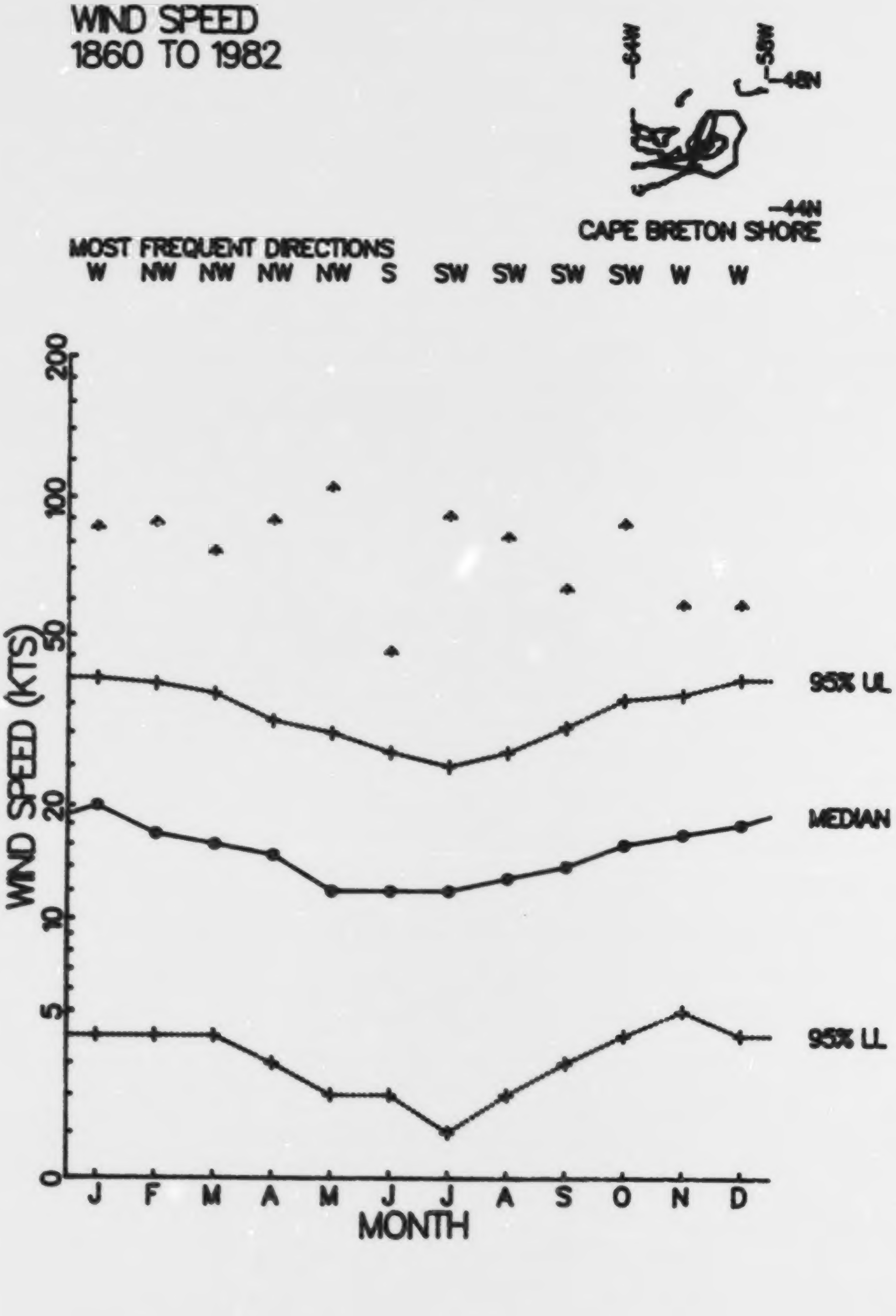
ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE


AIR TEMPERATURE
1860 TO 1982

CAPE BRETON SHORE

Appendix 3-2

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE



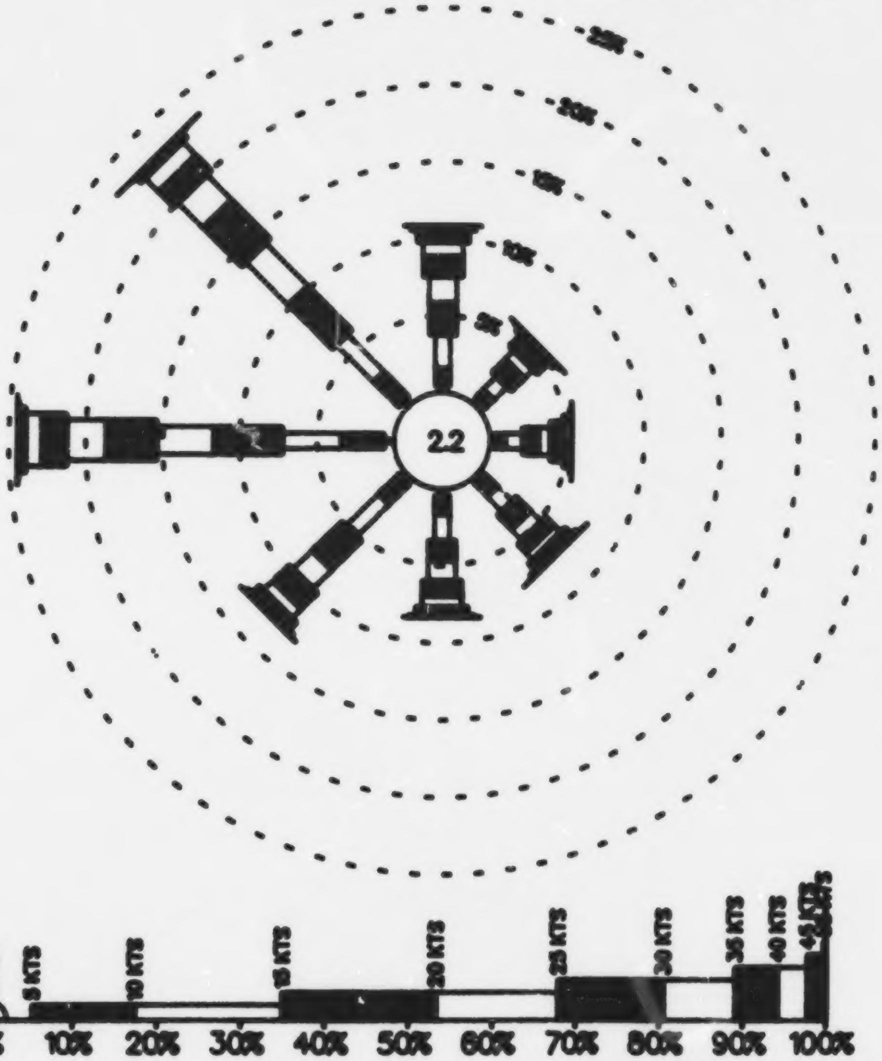
Appendix 3-3

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT
CANADIAN CLIMATE CENTRE

FREQUENCY OF
WIND SPEED
BY DIRECTION
WINTER
1860 TO 1982
N=7523

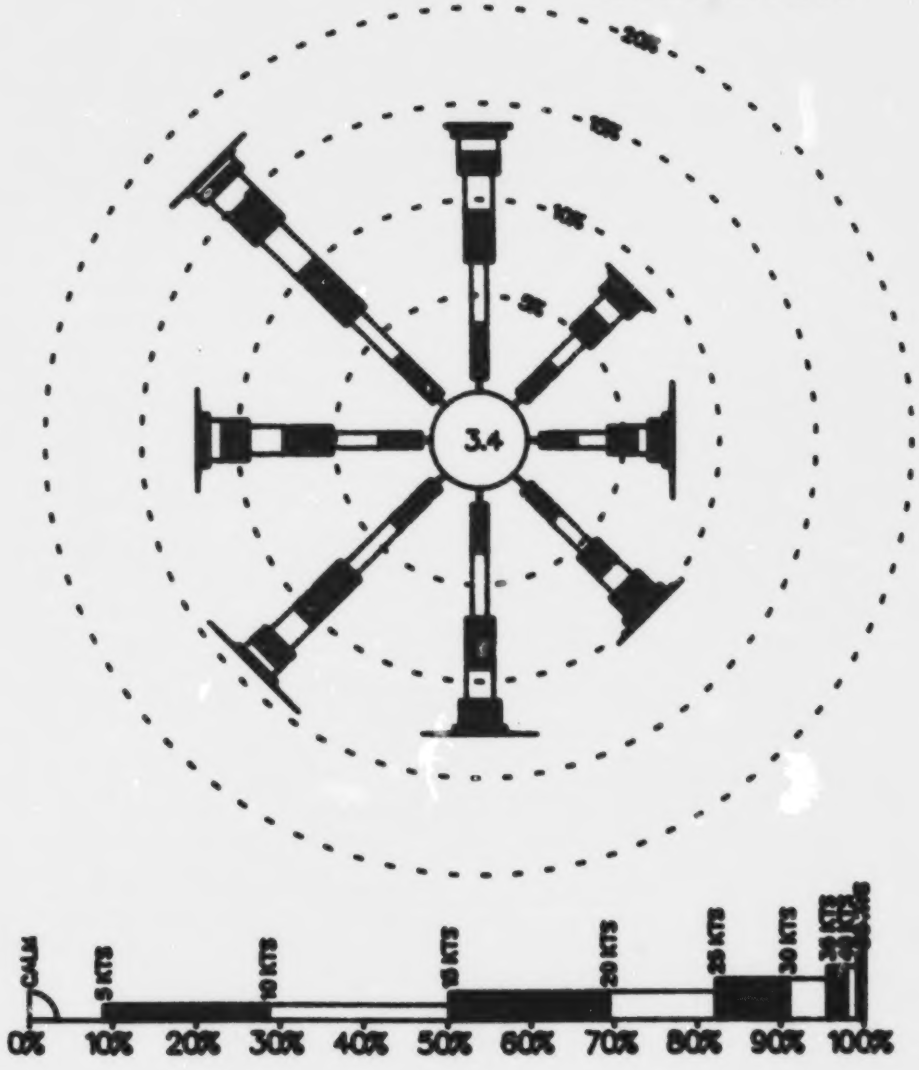
64W
56W
48N
44N

CAPE BRETON SHORE

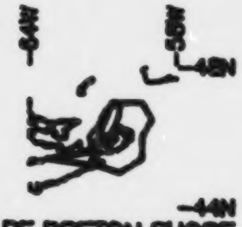


FREQUENCY OF
WIND SPEED
BY DIRECTION
SPRING
1860 TO 1982
N=7316

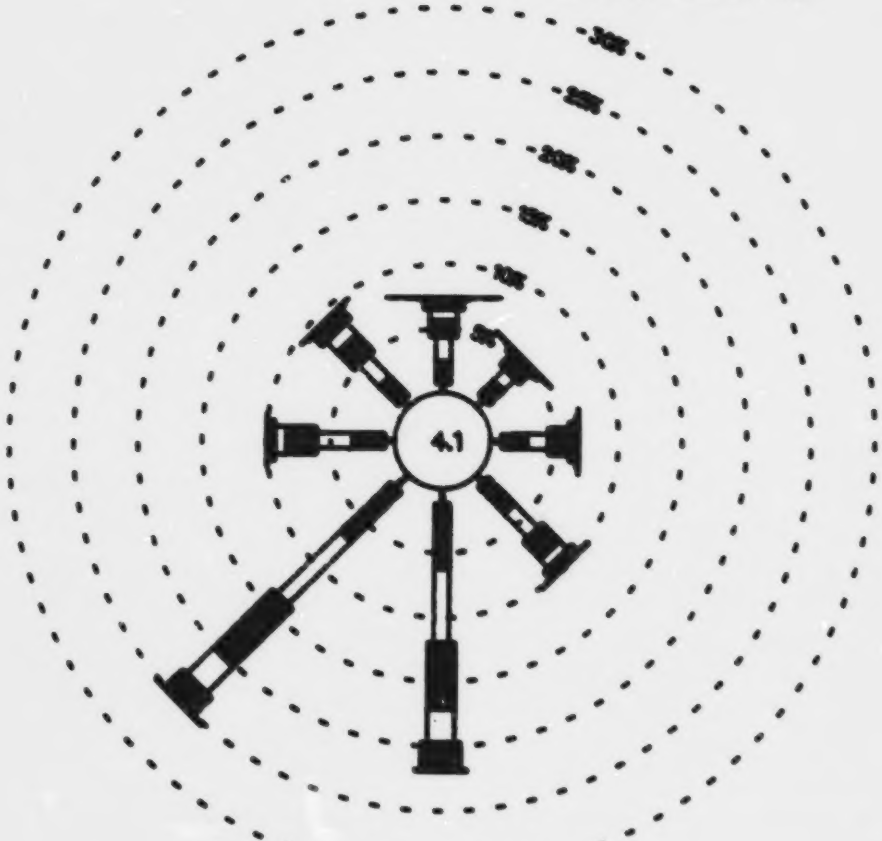
64W
56W
48N
44N
CAPE BRETON SHORE

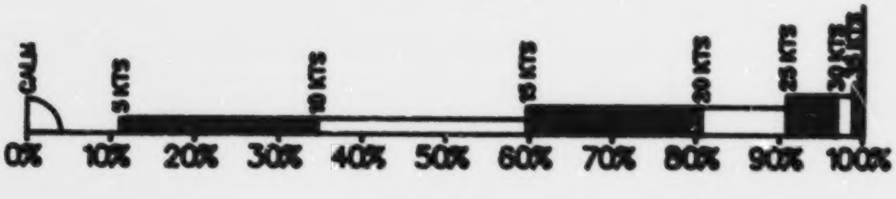


FREQUENCY OF
WIND SPEED
BY DIRECTION
SUMMER
1860 TO 1982
N=8292



CAPE BRETON SHORE



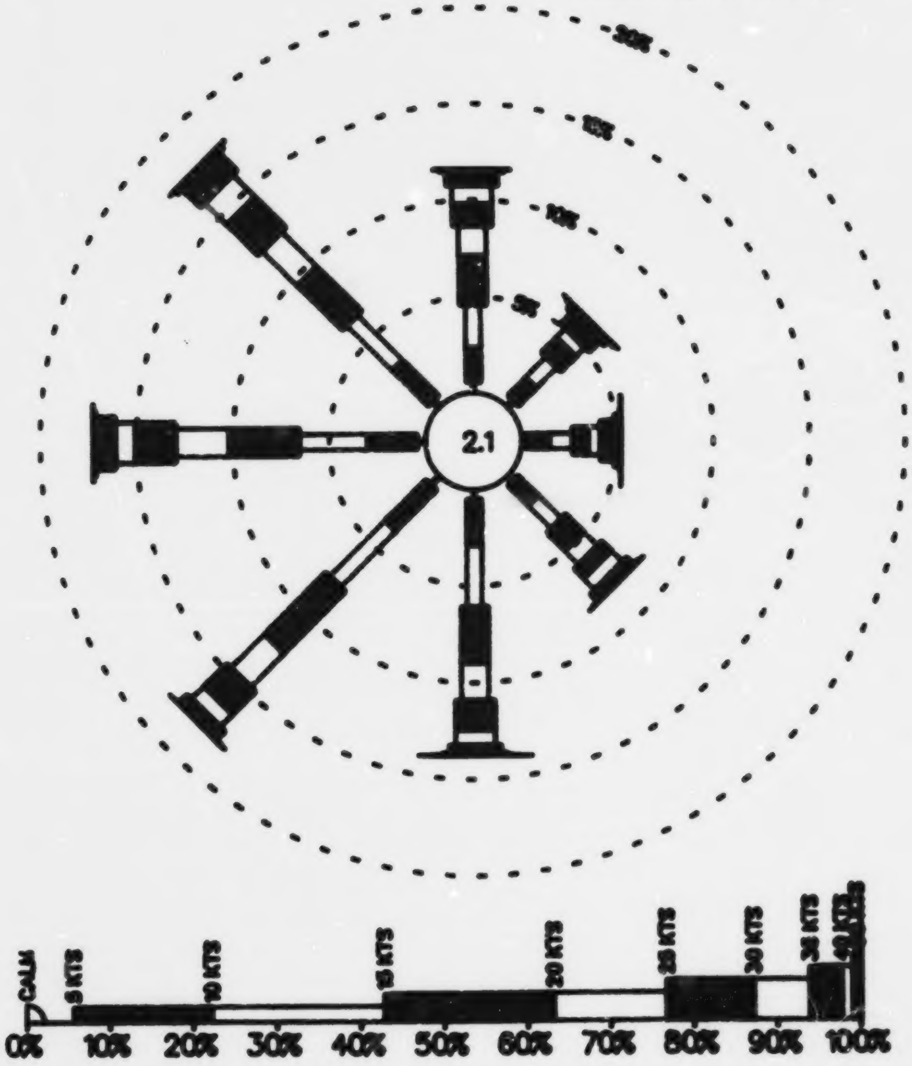


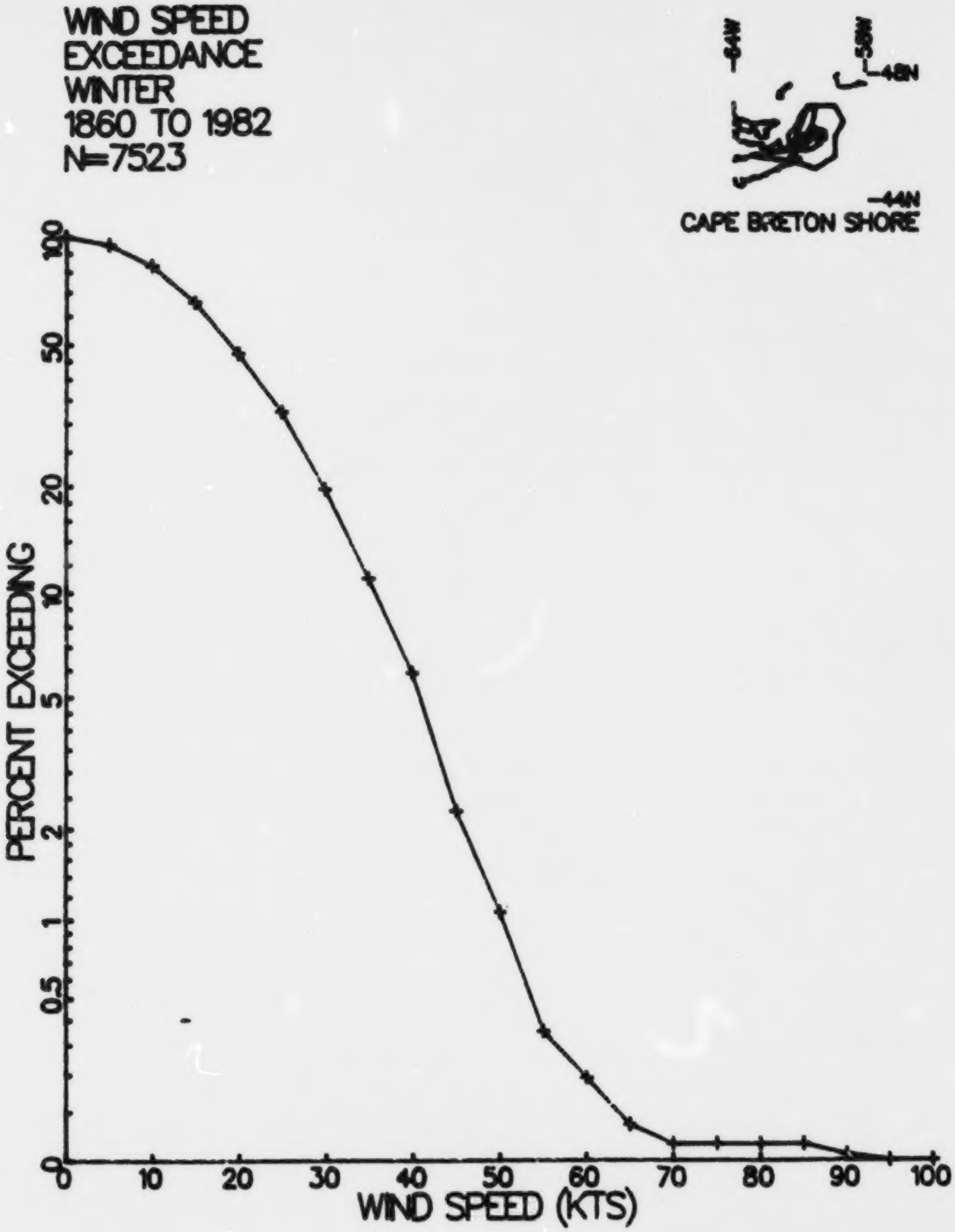
ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

FREQUENCY OF
WIND SPEED
BY DIRECTION
AUTUMN
1860 TO 1982
N=8901

-64W
-58W
-46N
-44N

CAPE BRETON SHORE

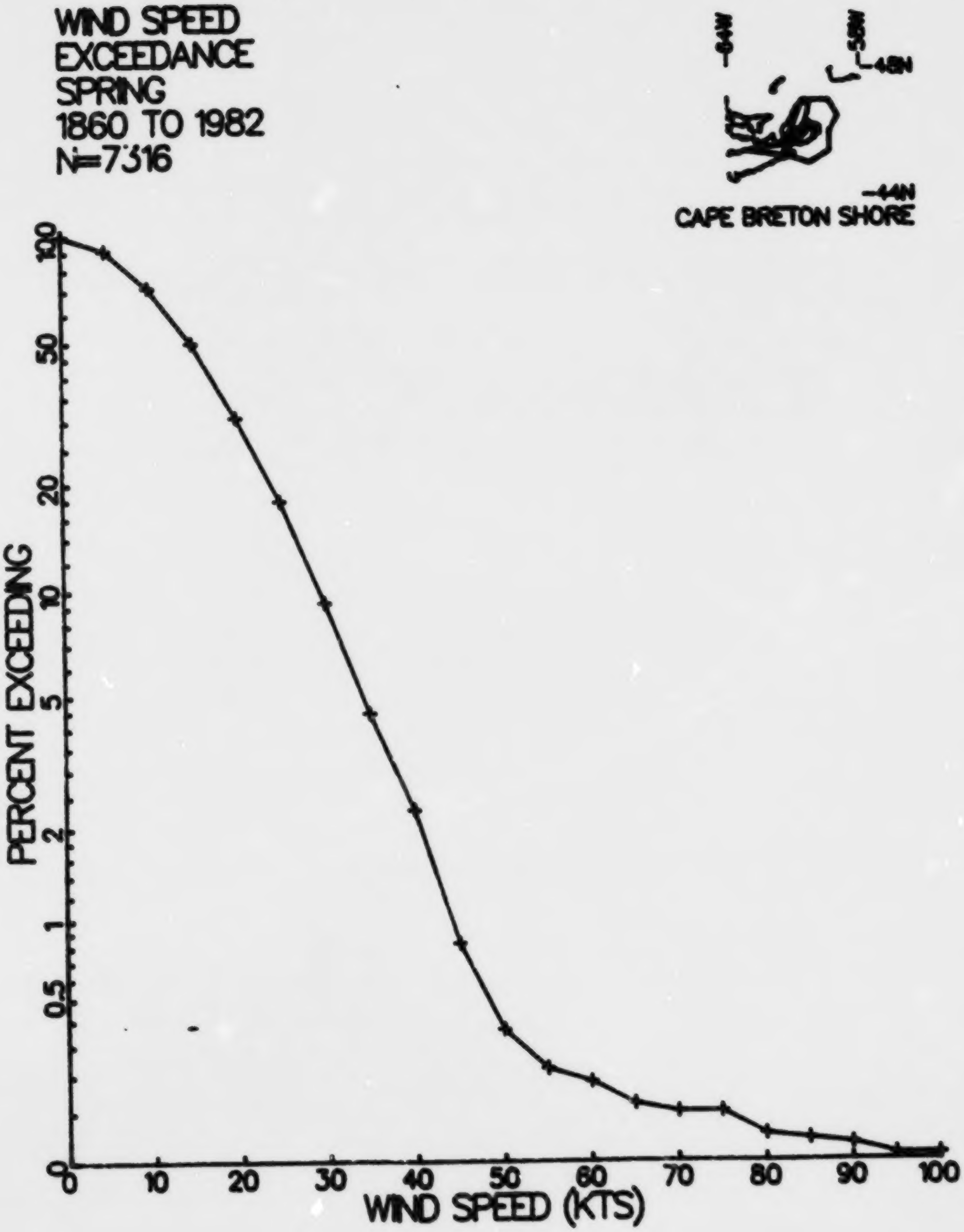


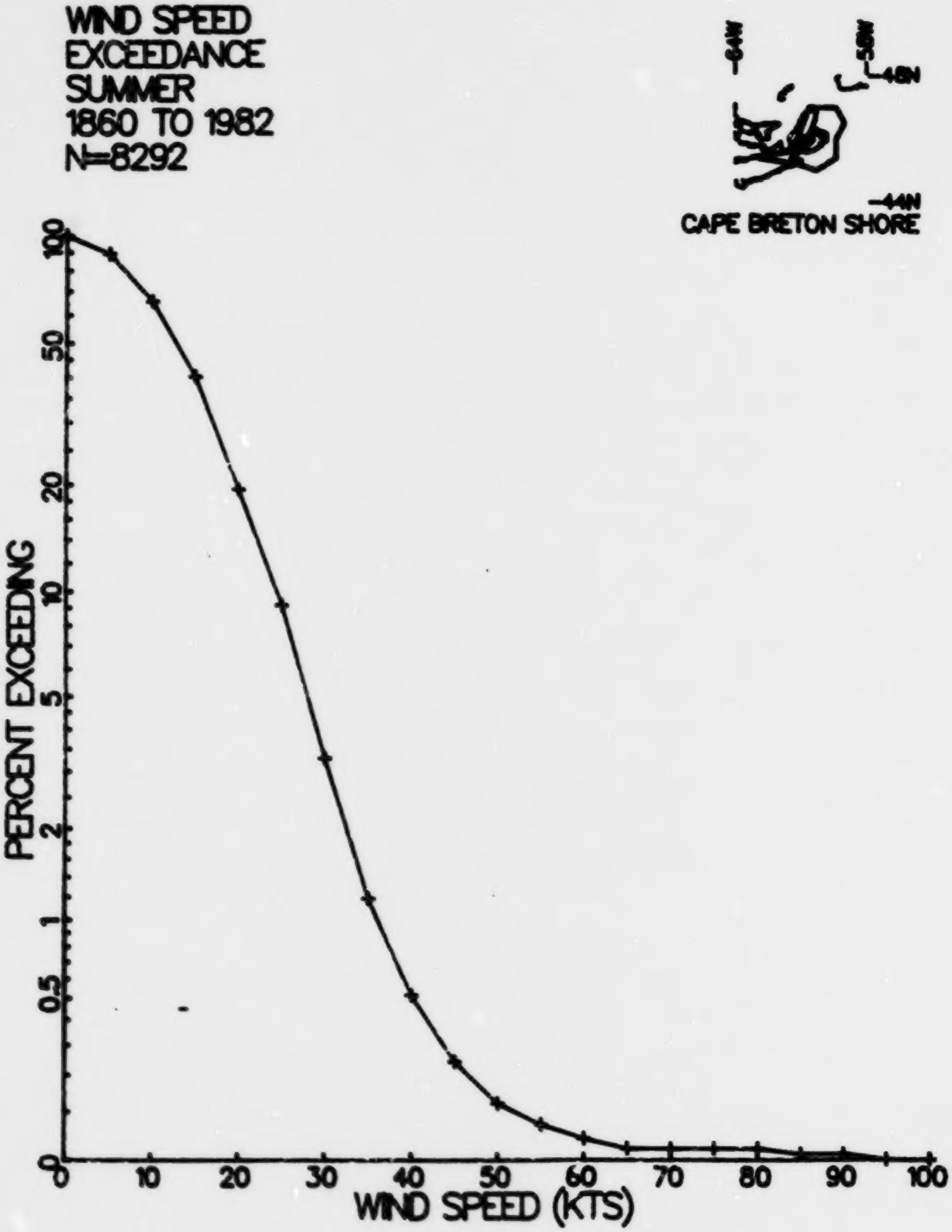


WIND SPEED
EXCEEDANCE
WINTER
1860 TO 1982
N=7523

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

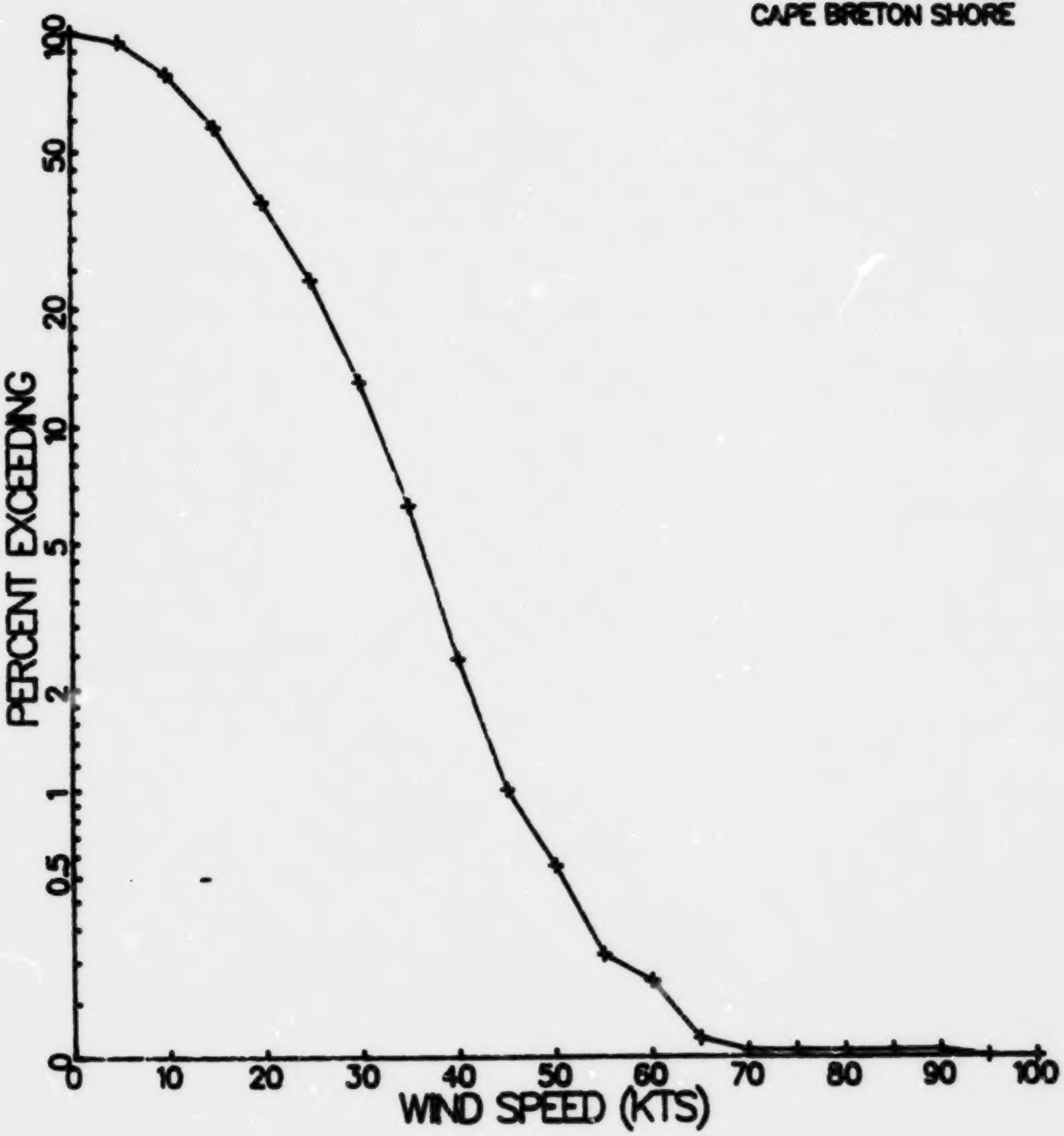
WIND SPEED
EXCEEDANCE
SPRING
1860 TO 1982
N=7316




WIND SPEED
EXCEEDANCE
SUMMER
1860 TO 1982
N=8292
64W
56W
46N
44N
CAPE BRETON SHORE
PERCENT EXCEEDING
100
50
20
10
5
2
1
0.5
0
WIND SPEED (KTS)
0
10
20
30
40
50
60
70
80
90
100

WIND SPEED
EXCEEDANCE
AUTUMN
1860 TO 1982
N=8901

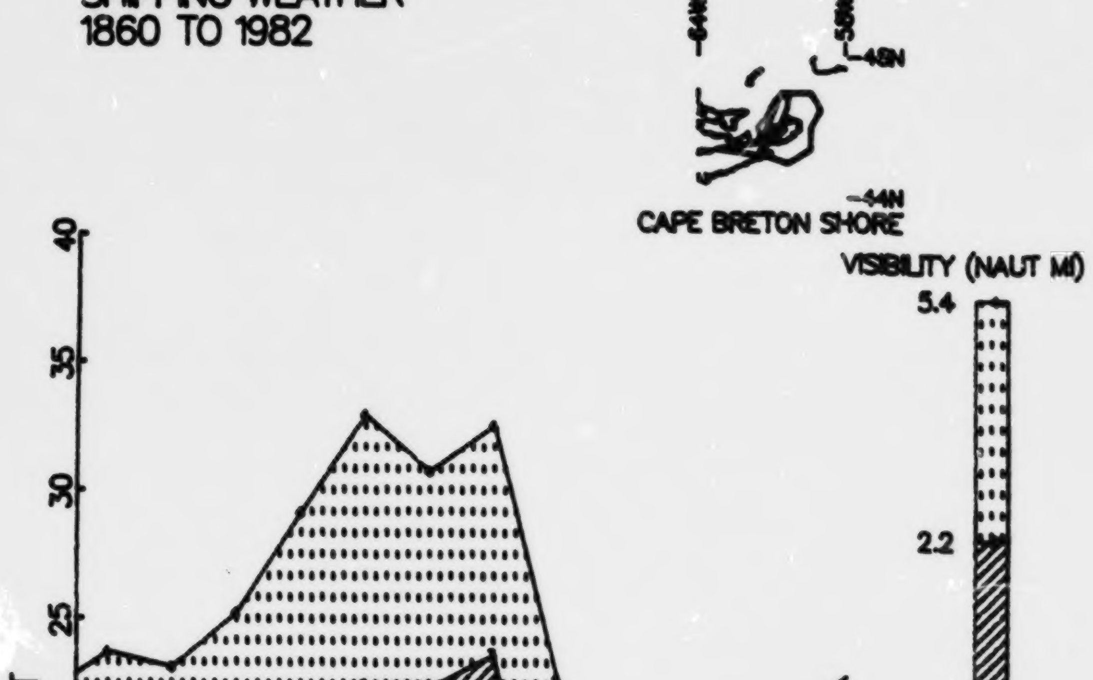
64W
58W
48N
44N
CAPE BRETON SHORE



Appendix 3-5

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

SHIPPING WEATHER
1860 TO 1982

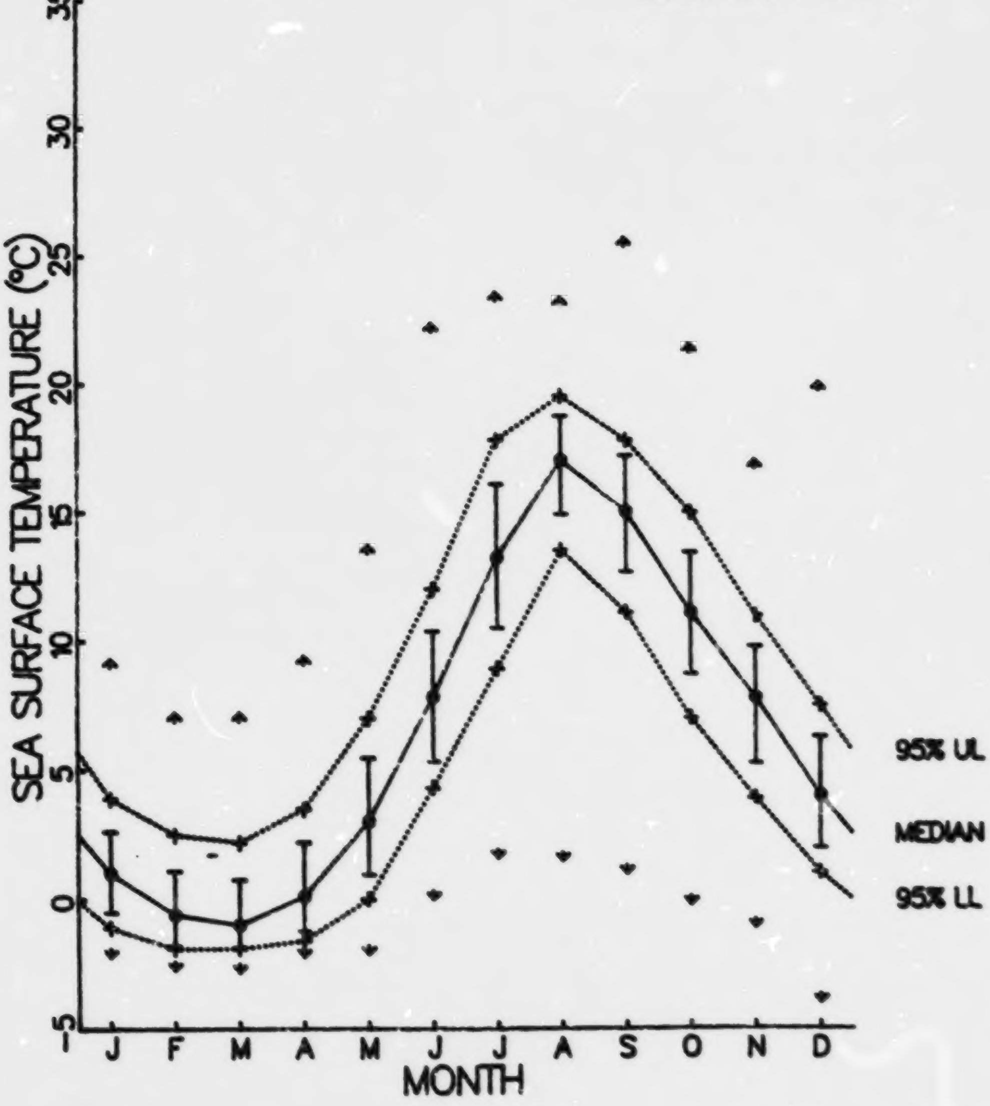


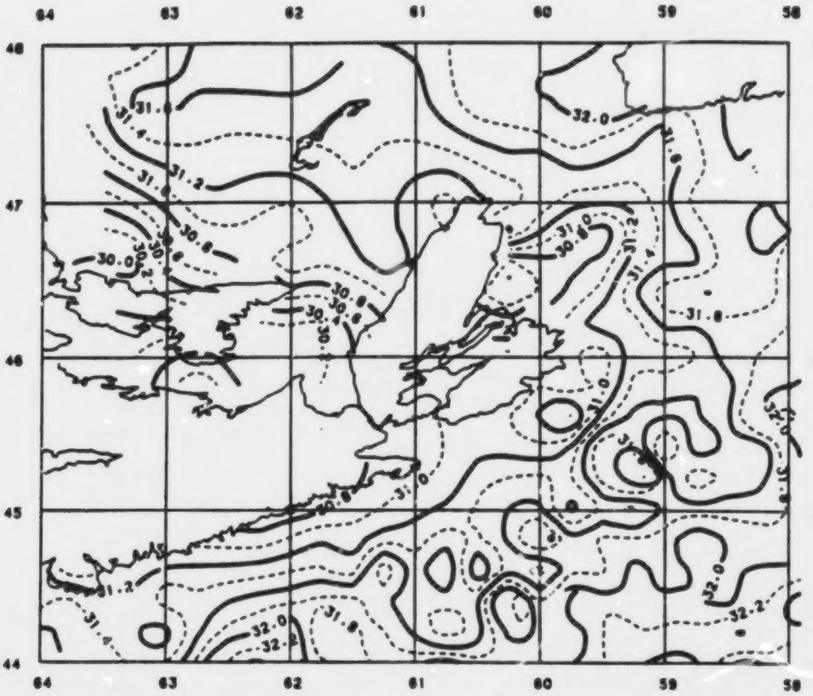
Appendix 3-6

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT
CANADIAN CLIMATE CENTRE

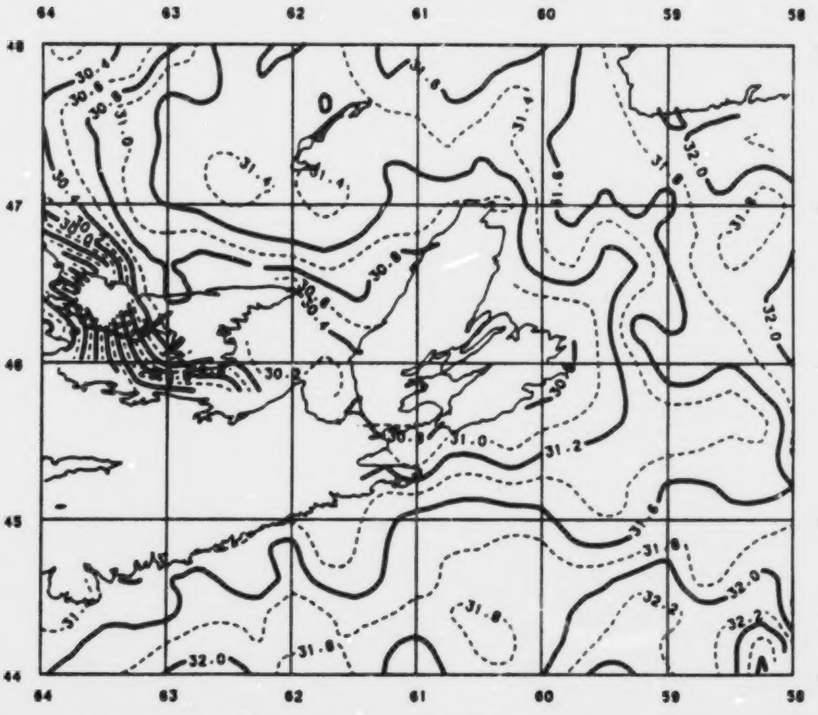
SEA SURFACE TEMPERATURE 1860 TO 1982

64W
58W
48N
44N
CAPE BRETON SHORE




64
63
62
61
60
59
58
48
47
46
45
44
31.0
31.4
31.2
30.8
30.0
32.0
31.6
31.8
31.0
31.2
32.2

SALINITY AT 25M JAN/FEB/MAR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63
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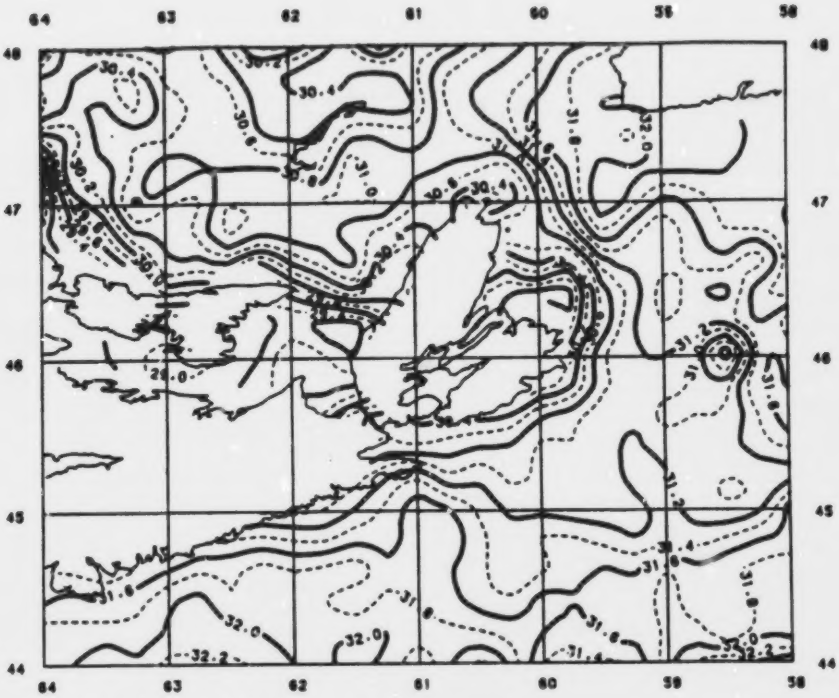
45
44
30.4
30.6
30.8
31.0
31.4
31.6
31.8
32.0
30.2
31.2
32.2

SALINITY AT 25M APR/MAY/JUN

(Source: Marine Environmental Data Service)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61
60
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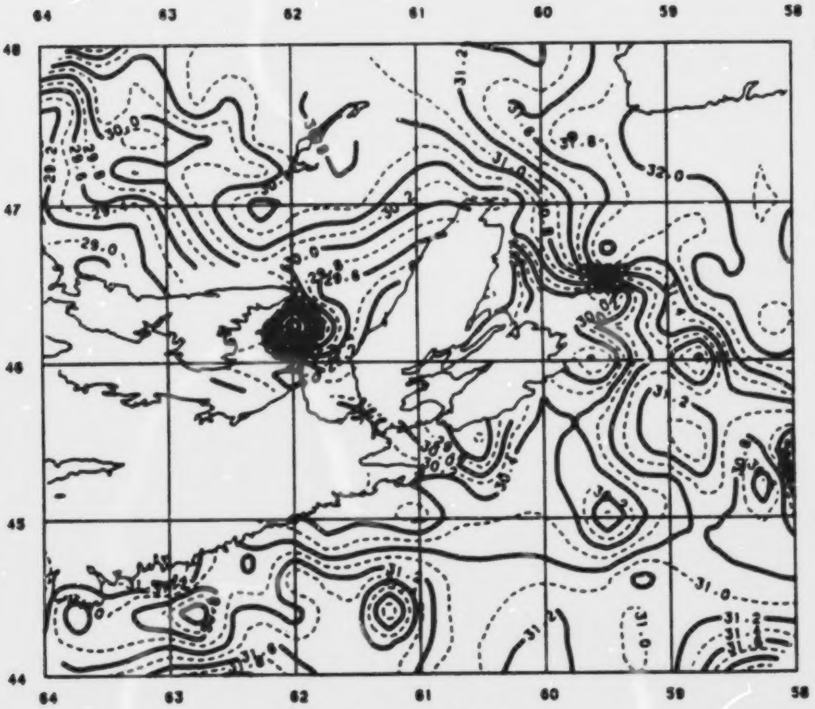
58
48
47
46
45
44
30.4
30.2
30.6
31.0
31.6
32.0
29.0
31.4
31.8
32.2

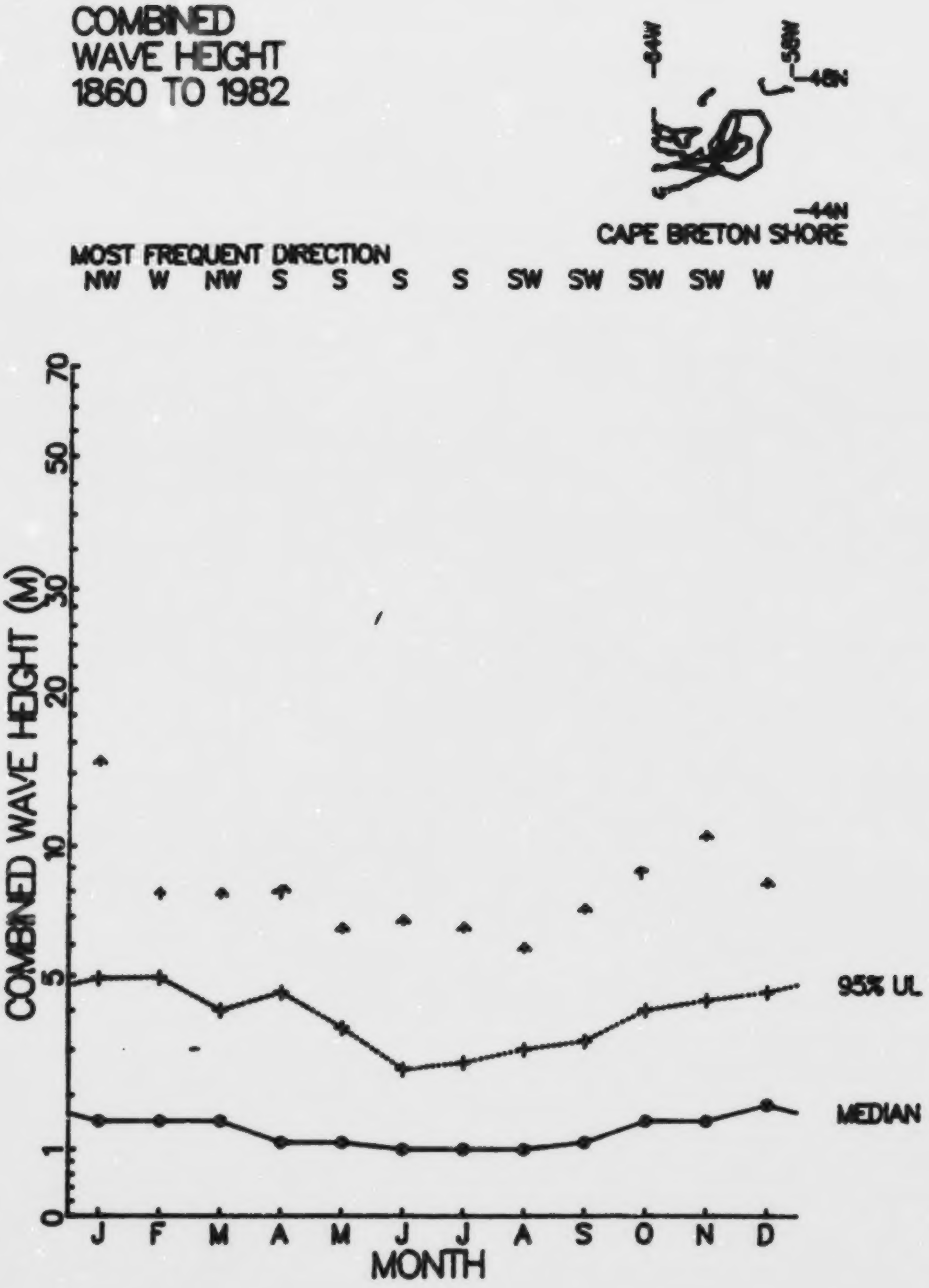
SALINITY AT 25M JUL/AUG/SEP


64
63
62
61
60
59
58
48
47
46
45
44
30.0
29.0
30.2
31.0
31.2
31.6
32.0

SALINITY AT 25M OCT/NOV/DEC

(Source: Marine Environmental Data Service)

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

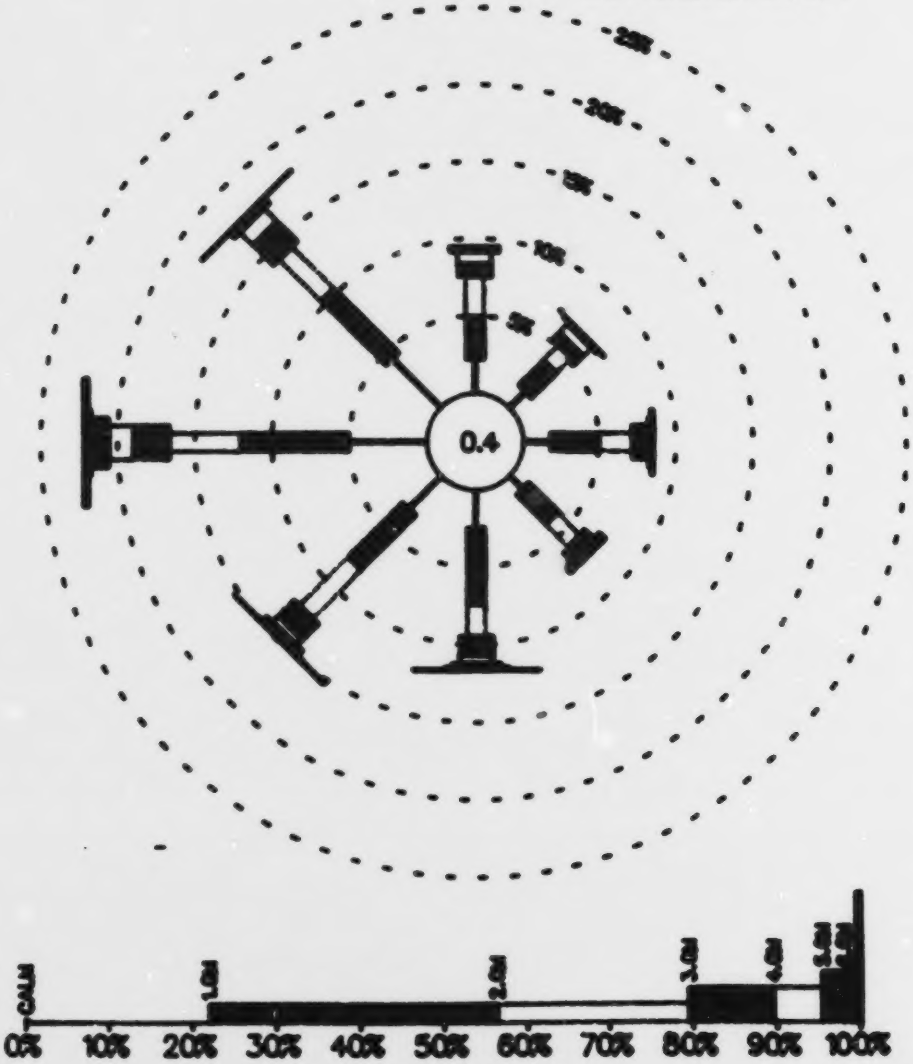


Appendix 3-9

ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT
CANADIAN CLIMATE CENTRE

FREQUENCY OF
COMBINED WAVE HEIGHT
BY DIRECTION
WINTER
1860 TO 1982
N=1316

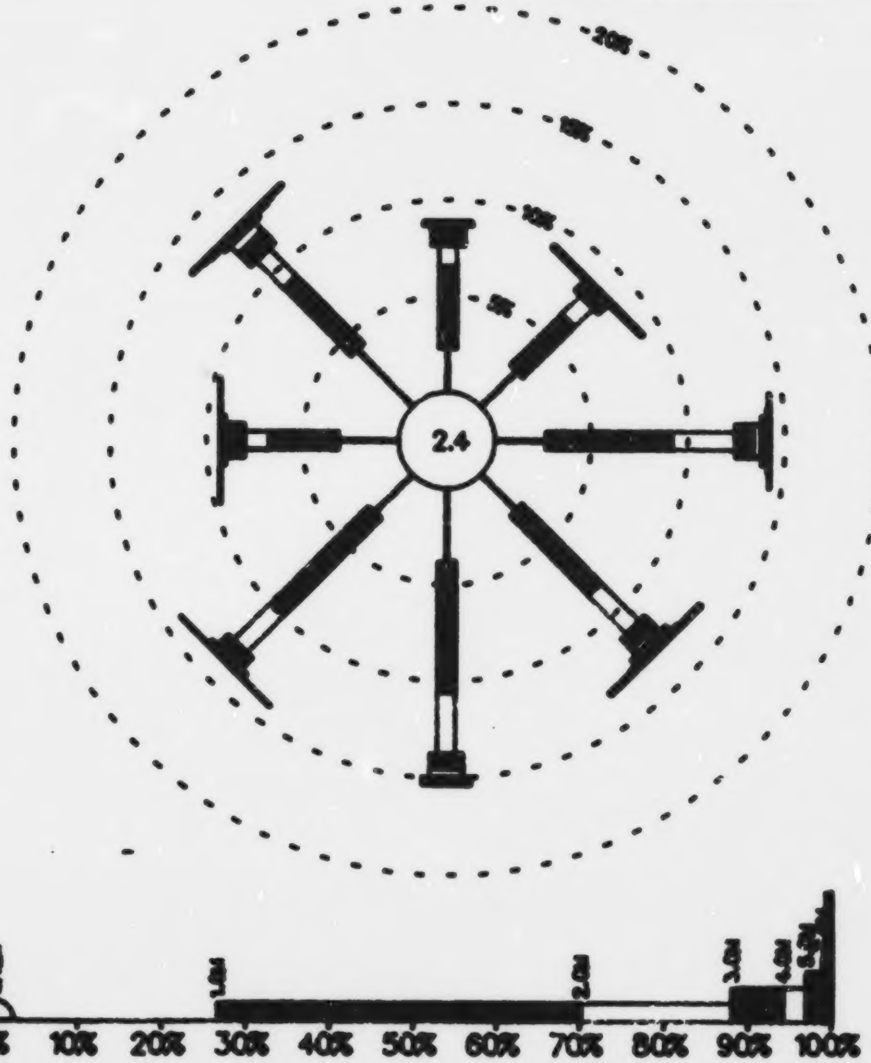
64W
56W
48N
44N
CAPE BRETON SHORE



FREQUENCY OF
COMBINED WAVE HEIGHT
BY DIRECTION
SPRING
1860 TO 1982
N=1407

64W
58W
46N
44N

CAPE BRETON SHORE

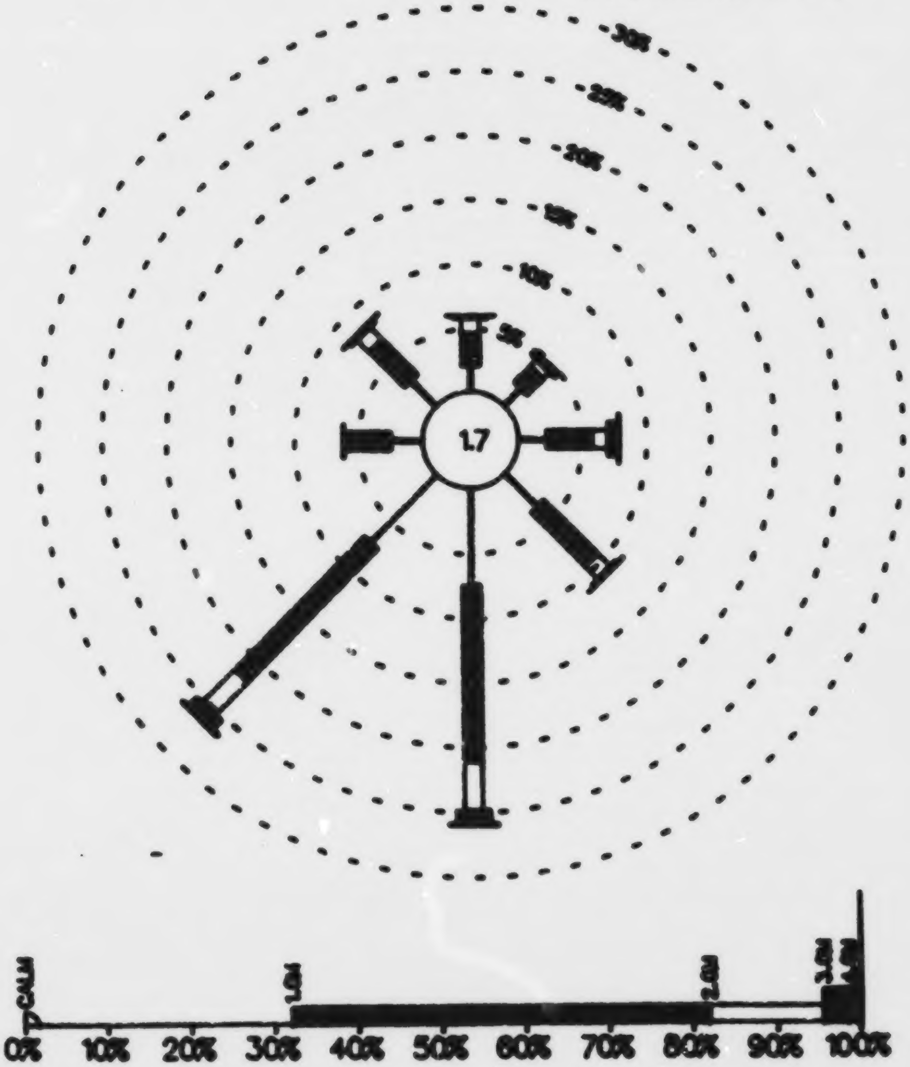


ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

FREQUENCY OF
COMBINED WAVE HEIGHT
BY DIRECTION
SUMMER
1860 TO 1982
N=2301

-64W
-58W
-48N
-44N

CAPE BRETON SHORE

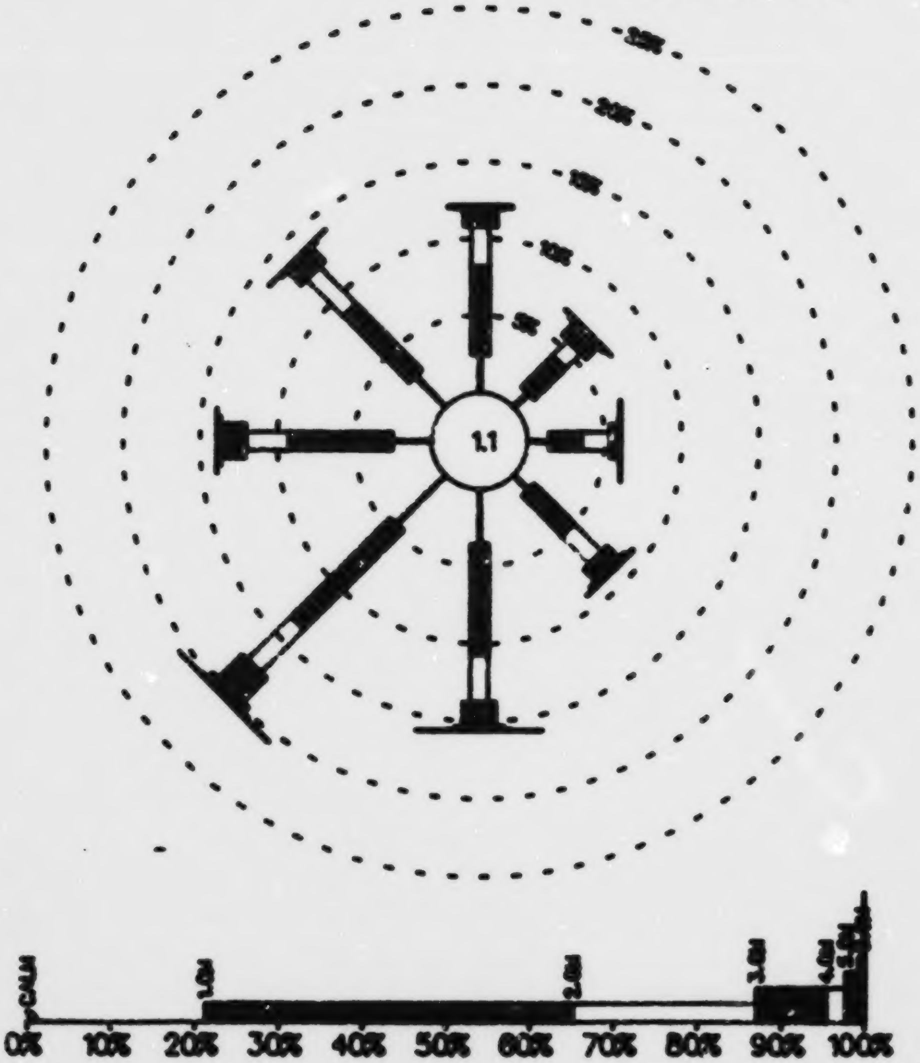


ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

FREQUENCY OF COMBINED WAVE HEIGHT BY DIRECTION AUTUMN 1860 TO 1982 N=2354

64W
58W
48N
44N

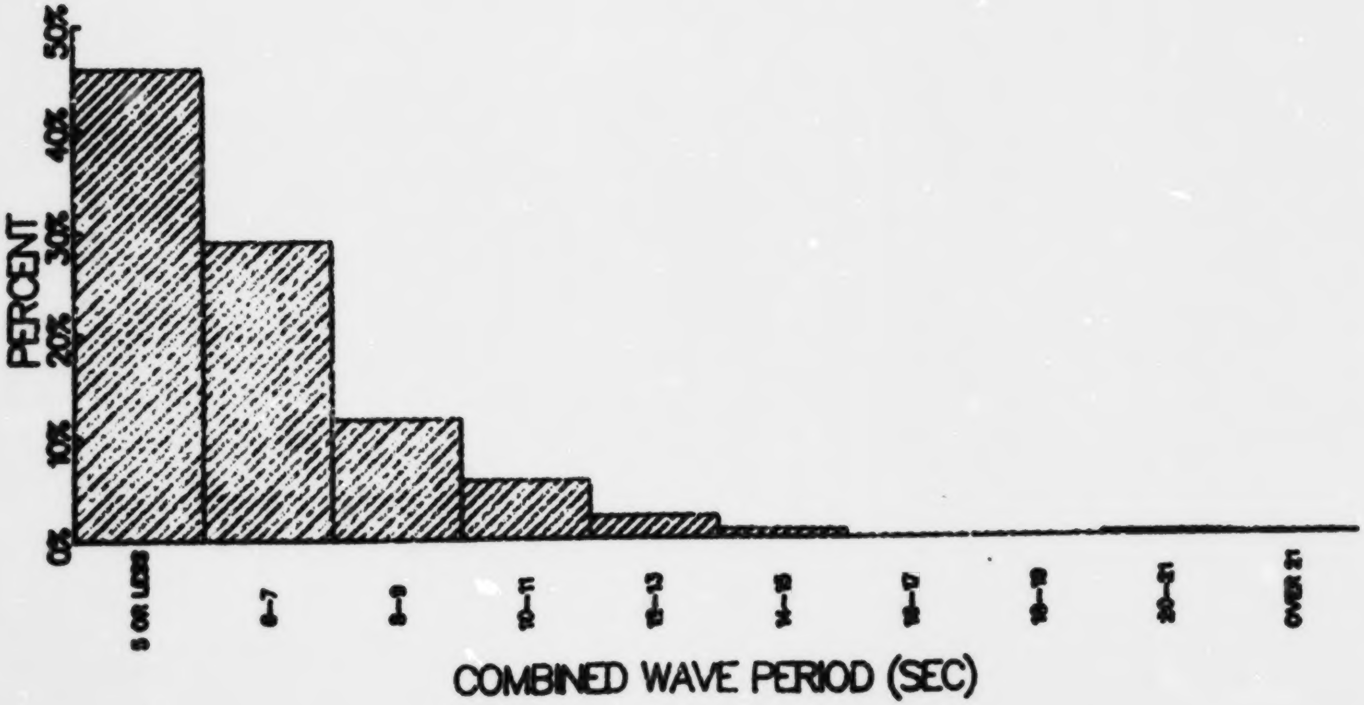
CAPE BRETON SHORE



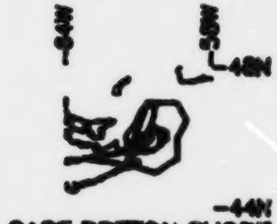
ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

COMBINED WAVE PERIOD FREQUENCIES
WINTER
1860 TO 1982
N=1316

-64W
-58W
48N
-44N
CAPE BRETON SHORE



COMBINED WAVE PERIOD FREQUENCIES
SPRING
1860 TO 1982
N=1407



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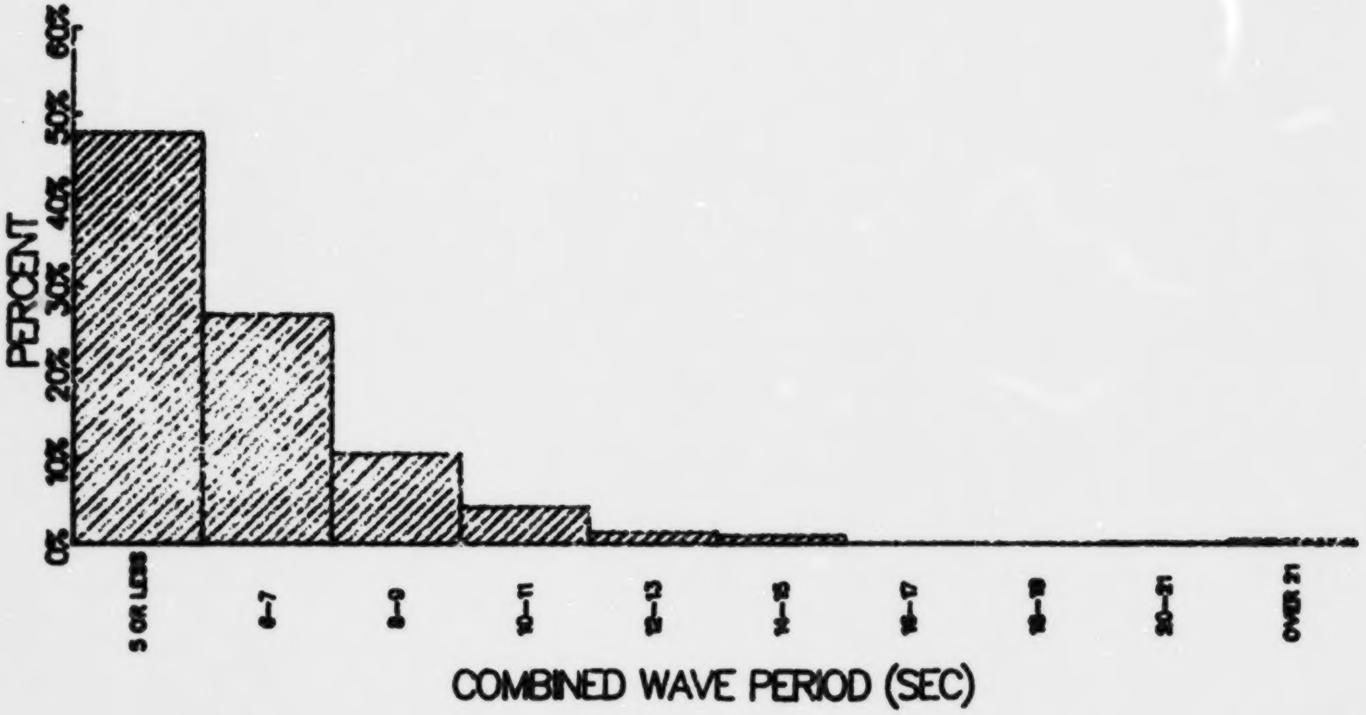
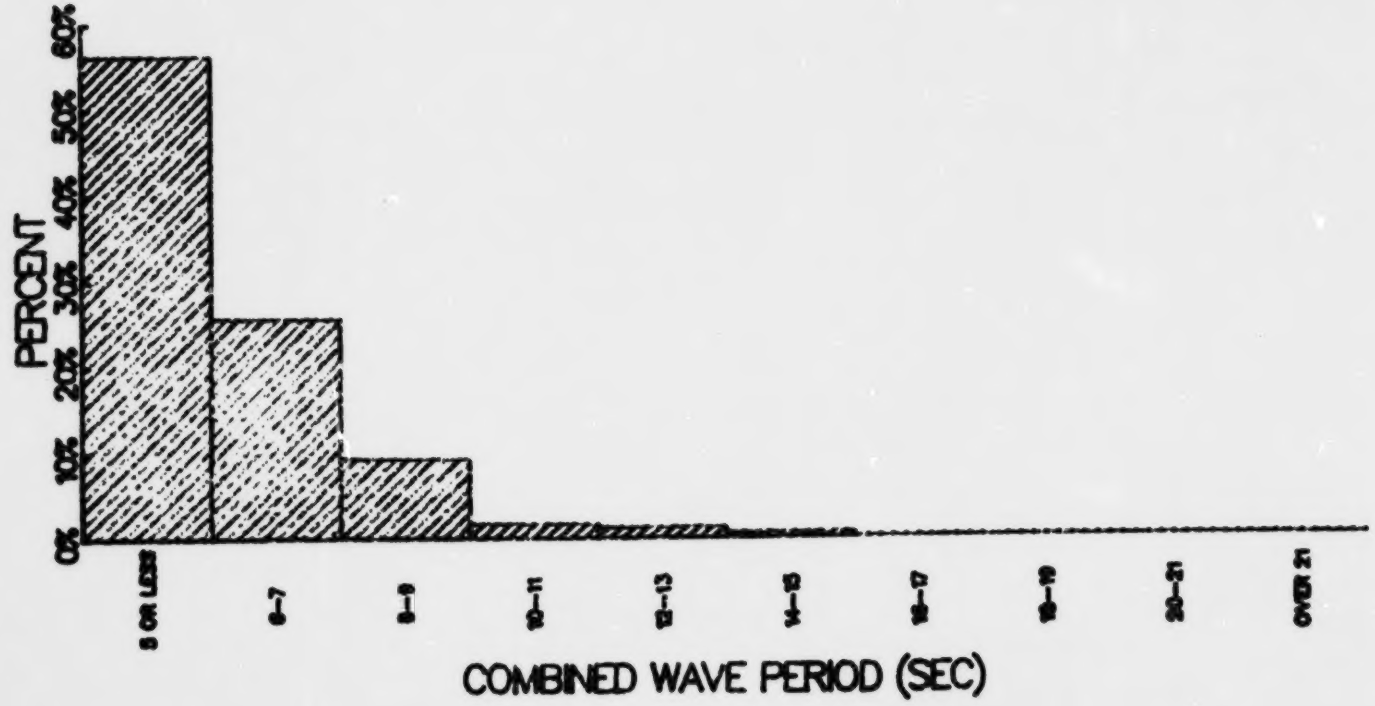


ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

COMBINED WAVE PERIOD FREQUENCIES
SUMMER
1860 TO 1982
N=2301

-64W
-58W
-48N
-44N
CAPE BRETON SHORE

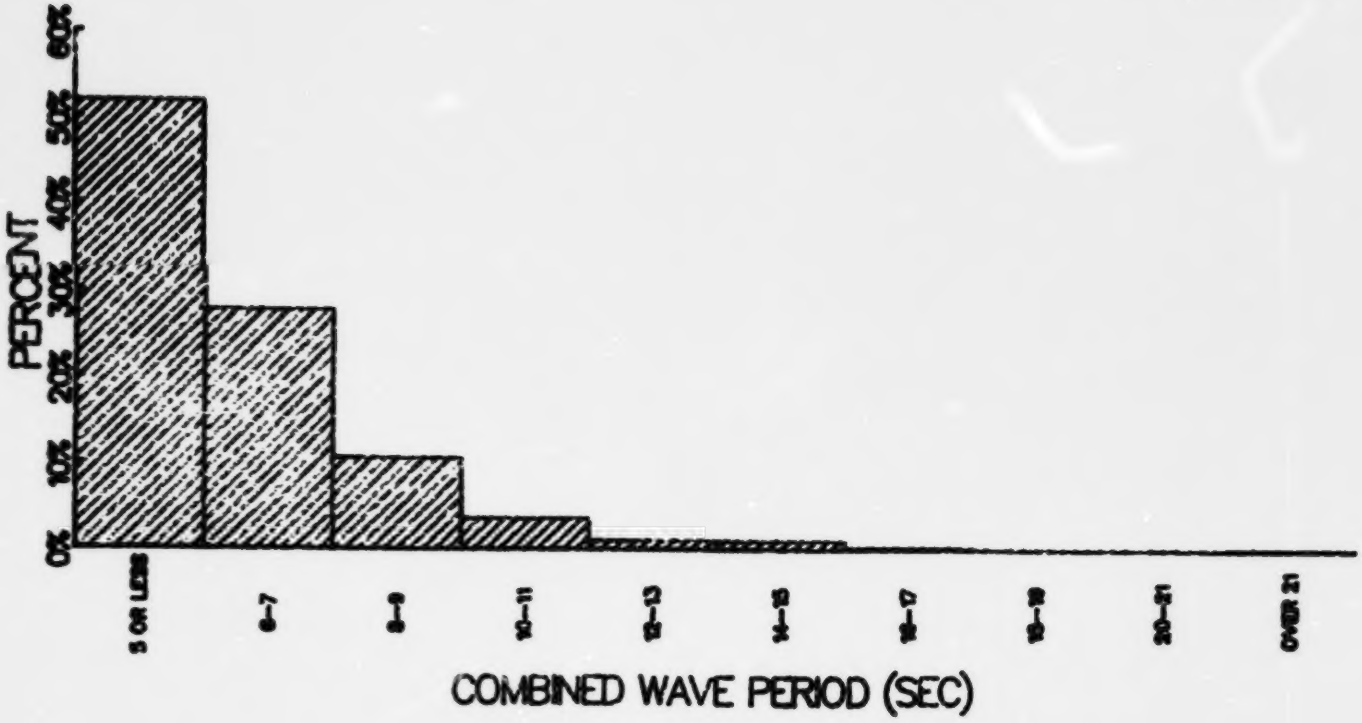


ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

COMBINED WAVE PERIOD FREQUENCIES
AUTUMN
1860 TO 1982
N=2354

64W
58W
48N
44N

CAPE BRETON SHORE

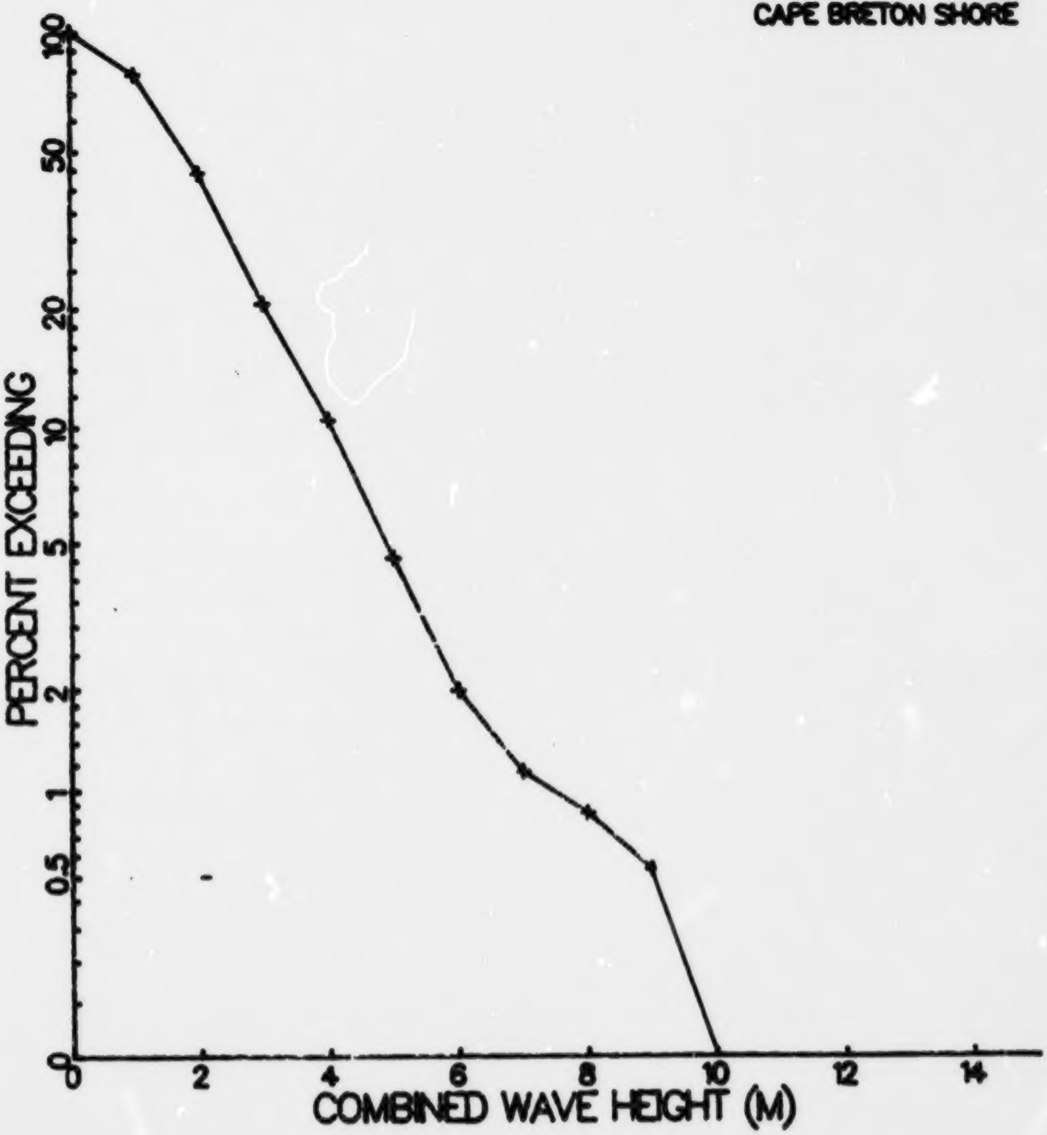


ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

COMBINED WAVE HEIGHT
EXCEEDANCE
WINTER
1860 TO 1982
N=1316

64W
56W
48N
44N

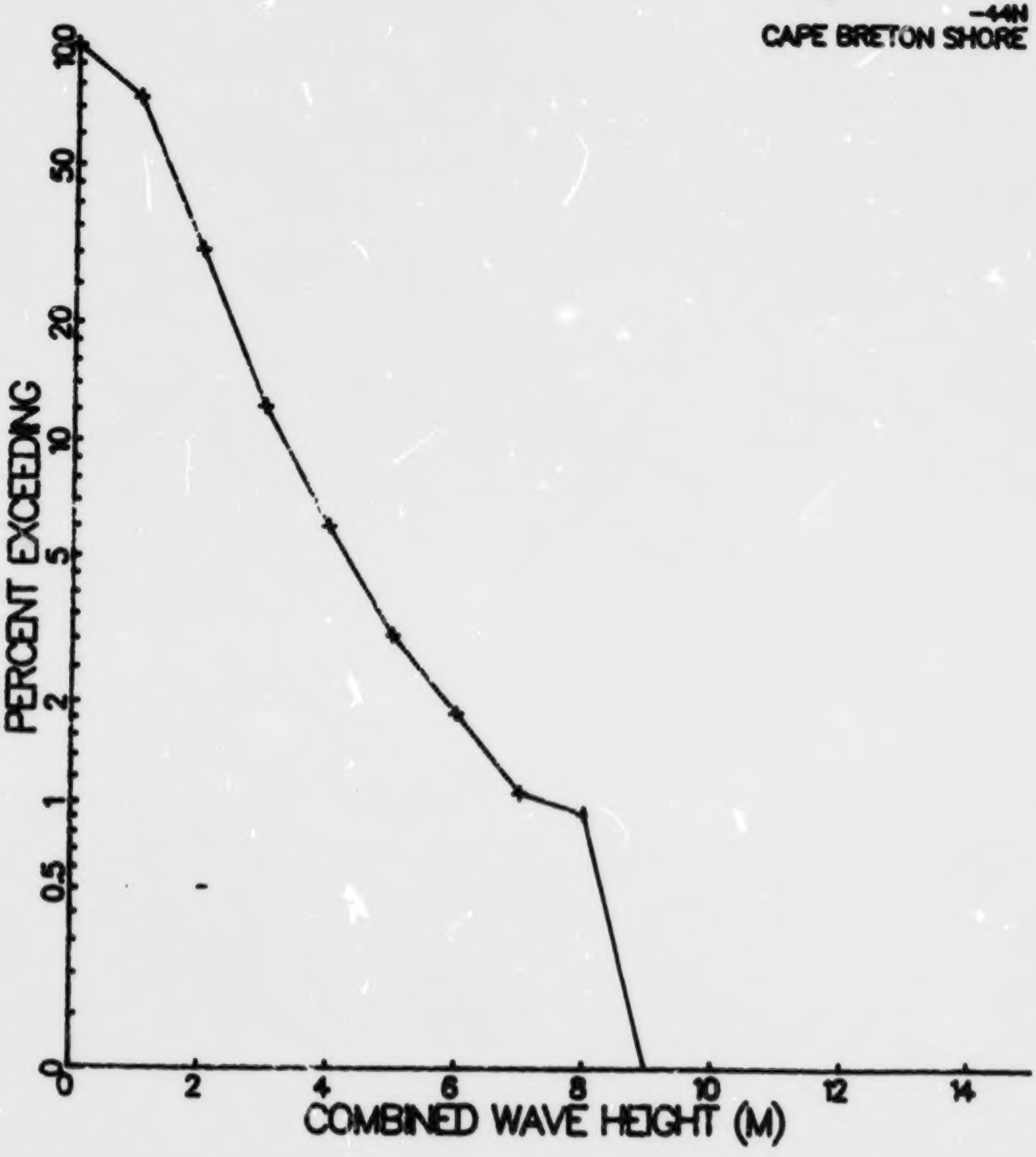
CAPE BRETON SHORE



ENVIRONMENT CANADA
ATMOSPHERIC ENVIRONMENT CANADIAN CLIMATE CENTRE

COMBINED WAVE HEIGHT
EXCEEDANCE
SPRING
1860 TO 1982
N=1407

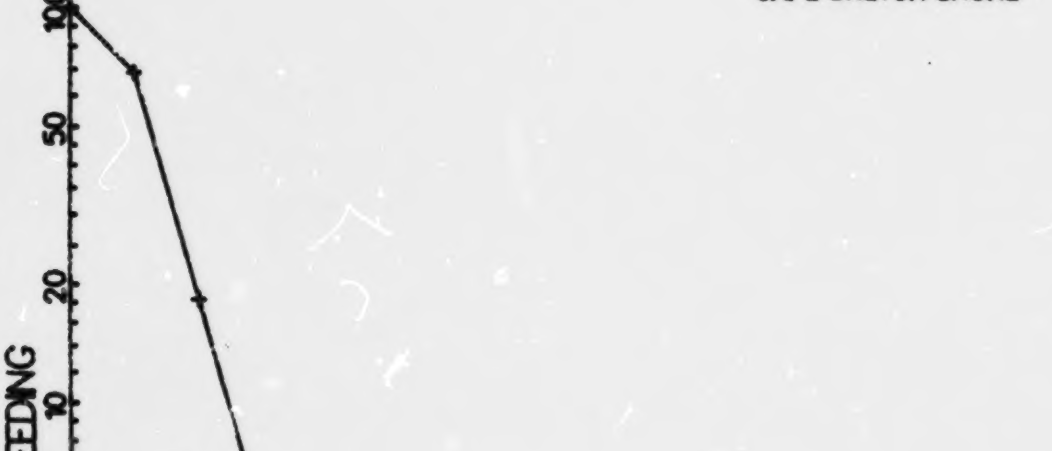
-64W
-58W
-48N
-44N
CAPE BRETON SHORE



COMBINED WAVE HEIGHT
EXCEEDANCE
SUMMER
1860 TO 1982
N=2301

64W
58W
48N
44N

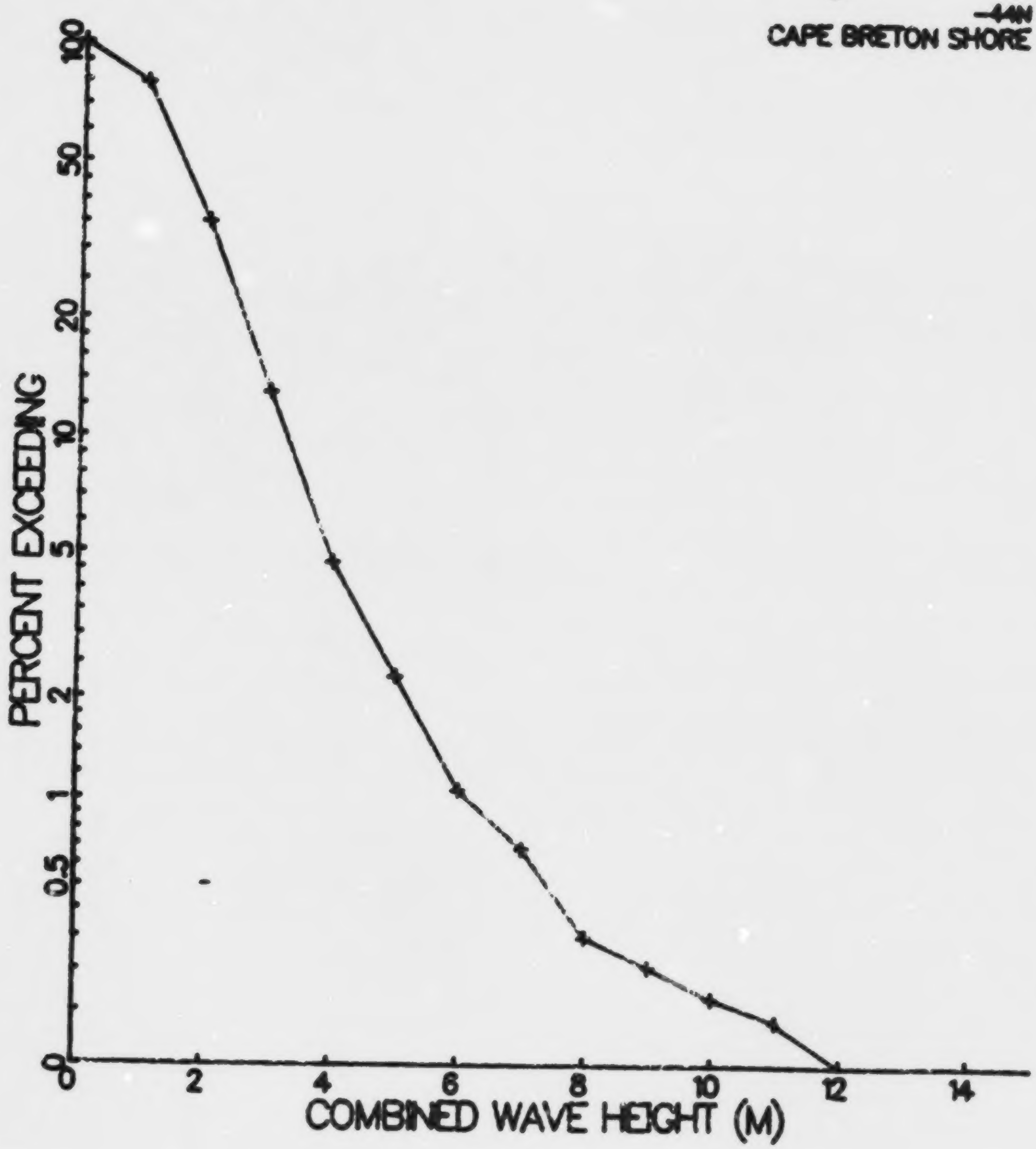
CAPE BRETON SHORE



COMBINED WAVE HEIGHT
EXCEEDANCE
AUTUMN
1860 TO 1982
N=2354

64W
58W
48N
44N

CAPE BRETON SHORE



APPENDIX 4

Appendix 4.1 - Multi-seam Mining at Smoky River
Paper by H.U. Bielenstein, P.L. Wright
and D. Mikalson

APPENDIX 4.2 - Strata Deformation Above Longwall Faces
Paper by A.N. Styler and R.K. Dunham

APPENDIX 4.1

Multi-seam Mining at Smoky River.

Paper by H U Bielenstein, P L Wright and D Mikalson

Energy, Mines and Resources, Canada

SIXTH INTERNATIONAL
STRATA CONTROL CONFERENCE
Banff, Canada, Septerber 23 - 28, 1977

TECHNICAL REPORTS

MULTI-SEAM MINING AT SMOKY RIVER

by

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INTRODUCTION

The Smoky River Coal Field is located 230 miles (370 km) west of Edmonton, Alberta (Figure 1). McIntyre Mines Ltd. began production in 1969. Although these coal deposits have been known since before the turn of the century, development had to await the resurgent interest in coal, the construction of a railway line and a new townsite (Grande Cache). Shipments of metallurgical coal have been made to Japan since 1970. Initial development was in underground workings in No. 4 Seam; a 20-foot (6.1 m) seam outcropping along the Smoky River valley (Figure 1). The No. 2 Mine workings extended about 1.3 miles (2.1 km) under the ridge, to a point where maximum overburden was over 1800 feet (550 m). The overburden pressures caused substantial plastic deformation of the coal, particularly floor heave.

Open pit mining was initiated at No. 8 Mine (Figure 1); its success led to the planning and development of No. 9 Mine, with a potential mineable reserve of over 90 million tons lying north of Sheep Creek. It was recognized early in the planning that a 2-mile (3.2 km) beltway, through the ridge between Sheep Creek and Smoky River would eliminate 8 miles (13 km) of truck haulage and deliver the run-of-mine coal directly into the cleaning-plant circuit. The operational cost savings in using a beltway would be substantial, both in haulage costs and road maintainance.

Initially, it was planned to drive the beltway along the easterly side of No. 4 Seam workings, but the plastic deformation of the coal precluded permanent openings in this seam. Consideration was then given to other horizons, resulting in a test mine in No. 11 Seam, 340 feet (104 m) stratigraphically above No. 4 Seam. Work commenced in 1973, and after an efficient mining system was established, a three-entry development system was started, for the beltway through the ridge. To expedite completion of the beltway, entries were also driven from the Sheep Creek side of the ridge; the connection was made in February 1975.

The No. 4 Seam workings were already in existence when the decision was reached to develop the beltway in No. 11 Seam. These entries, therefore, had to pass over developed, depillared and solid No. 4 Seam coal. Continuation of the depillaring operations in No. 4 Seam was required by contract commitments. The beltway, therefore, was to be subjected to a progressive undermining in No. 4 Seam.

A joint project between McIntyre Mines Ltd. and the Mining Research Laboratories, Canada Centre for Mineral and Energy Technology, Department of Energy, Mines and Resources, was started, to monitor the deformation of No. 11 Seam workings and overall strata behaviour. The objectives of this joint project were to measure the deformation of roadways and pillars in No. 11 Seam, and of the strata above No. 4 Seam, in relation to the depillaring operations in No. 4 Seam; and to interpret the interaction between the workings in the two seams.

GEOLOGIC AND OPERATIONAL SETTING

GEOLOGY

The coal measures in the Smoky River area are of Lower Cretaceous age, and occur in the lower Luscar Formation [1]. Recent work by J.R. McLean (personal communication) has shown that Stott's [2] stratigraphic sub-division can be extended southward into the Smoky River area; of these the Moosebar Formation of marine shales is underlain by the Gething Formation and overlain by the lower Commotion Formation; both are coal-bearing and represent alluvial plain and/or deltaic depositional environments. Current mining operations are restricted to the lower Commotion Formation, which comprises interbedded sandstones, shales, siltstones and coal. Individual rock units are discontinuous and detailed correlation is almost impossible although for short distances the coal seams can be used as marker horizons (Figure 2).

Structurally, the Smoky River Coal Field lies in the Cordilleran thrust-and-fold belt. Numerous easterly directed thrust faults repeat the stratigraphic succession in this area, and thicken the sedimentary pile. Folding, within individual thrust plates gives a spectrum of bedding dips from horizontal to near vertical and overturned.

In the No. 2 Mine area, underground workings have been developed in No. 11 and No. 4 Seams. The complex stratigraphy is illustrated in Figure 2, using available drill hole and development data. One major coal seam (No. 10) lies between the two seams being worked presently. Another thin seam, 2 to 4 feet (0.6 to 1.2 m) thick, is found 5 to 15 feet (1.5 to 4.5 m) below No. 11 Seam.

The No. 2 Mine area is bounded to the east and west by major anticlines - Barrett and McEvoy anticlines respectively. Both No. 11 and No. 4 Seam workings are confined to the nearly flat-bottomed syncline (Winder Flats); the limbs have gentle dips of up to 25° (Figure 3). Numerous small thrust faults with a stratigraphic throw of less than seam-thickness have been encountered in the No. 4 Seam workings.

MINING OPERATIONS

Underground mining in the Smoky River area is carried out by the room-and-pillar method [3]. Individual panels are usually developed with a three-entry system driven along strike on the down-dip side of the panel. Rooms are developed in the panel and pillars are extracted on retreat and down the dip. Continuous miners (Lee Norse CM455 or Joy 10CM) are used to cut rooms 18 feet (5.5 m) wide by 8 to 10 feet (2.4 to 3 m), the height is dependent on the area being mined. Coal is transported from the continuous miner by Joy

10SC shuttlecars, off-loaded through a Stamler breaker-feeder onto a belt-conveying system which discharges on the surface to the raw-coal stockpile at the cleaning plant. The roof support, generally used, is a 4-foot by 4-foot (1.2 m by 1.2 m) bolt pattern, utilizing tensioned roof bolts with expansion-shell anchors. In No. 4 Seam 6-foot (1.8 m) bolts are used, whereas in No. 11 Seam, where the roof is more compentent, both 4-foot (1.2 m) and 6-foot (1.8 m) bolts are installed. The bolts are installed with rubber-tired or tracked Fletcher roof-bolter machines. Where required, both in No. 11 and No. 4 Seams, this support is augmented by timber and/or steel girders; support at main intersections consists of steel girders on wooden cribs.

Retreat mining in the last two panels of No. 4 Seam workings was started in 1973, before the beltway in No. 11 Seam had been given final approval. To meet contract commitments the underground mines were scheduled to produce 4000 long tons of raw coal per day. This restraint had to be included in the decision to proceed with the beltway in No. 11 Seam, since it would be exposed to progressive undermining as depillaring operations continued in No. 4 Seam. Figure 4 shows the extent of pillar extraction when the beltway was started, when the beltway was completed, and in August 1976.

Floor heave has been a continuous problem in both seams. In No. 4 Seam, where the immediate floor is the bottom 10 feet (3 m) of the seam, floor clean-up operations, called 'brushing', are an easy method of getting more coal. In No. 11 Seam, shale floor must be brushed in order to maintain the size of the openings.

INSTRUMENTATION

Measurements on the interaction between the seams had to be carried out from the entry system in No. 11 Seam. The constraints for instrumentation included non-interference with the mining operations and long-term availability. It was envisaged, in 1974, that pillar extraction would continue in No. 4 Seam for at least two years. The measurements chosen for this study include levelling of the roof, roadway convergence, roof-to-floor pressure, pillar deformation, and strata deformation between the seams. The instrumentation installed in the No. 11 Seam workings is described below; generally instrument design was simple and robust, and the manual read-out ensured that instrument sites were visited frequently for visual inspections.

Instrumentation was installed to be accessible from the supply roadway, No. 2 Entry; the beltway and the return airway were labelled No. 3 and No. 4 Entry respectively (Figure 5). Locations within No. 11 Seam workings are referred to by cross-cut number, where '0' cross-cut is 270 feet (82.3 m) inbye the No. 2 Entry portal. Within this system cross-cut 45 is vertically above the furthest workings in No. 4 Seam.

Survey levels

Levels in No. 2 Entry were run approximately every month by the mine staff. A Cooke Engineering Level was used with a 5-foot sectional rod. Various bench marks were established as part of the normal mine surveying as the beltway was developed. Additional levelling points on roof bolts were established at the intersections with even-numbered cross-cuts, and on the casing of the strata deformation holes. The accuracy of the levelling was in the order of ± 0.1 feet (3 cm) for intermediate points. The levels were tied back to the original bench marks to ensure closure.

Convergence rods

The convergence rods, used to measure roadway deformation perpendicular to the seam, were a very simple design: two telescoping sections of electrical conduit were held apart by a washer and hollow rubber-stopper arrangement; a 30-cm ruler was clamped to the smaller-diameter section. Convergence readings could be taken directly to ± 1 mm and the rulers could be easily reset after about 20 cm of convergence. In some cases it became necessary to shorten each section of conduit to allow for further telescoping. This type of rod worked very well on convergence, but when a few rods began to fall over because of roof-to-floor divergence, the design was changed and a steel compression spring was substituted for the rubber stopper. The rods were set up perpendicular to the seam, with the base on a short plank buried in the floor, and the top pushed against the head of a roof bolt. More than 30 convergence rods were installed (see Figures 5 and 6 for locations).

Roof-to-floor pins

Convergence rods were designed to measure only roadway deformation. It was anticipated that the 4-foot (1.2 m) coal seam lying about 15 feet (4.5 m) below the No. 11 Seam floor (Figure 2) would influence the behaviour of the mining floor. It was, therefore, decided to obtain convergence measurements between the floor of the underlying seam and a point about 6 feet (1.8 m) above the roof of No. 11 Seam.

A 2 3/8-inch (6 cm) diamond-drill hole was drilled downward perpendicular to bedding to a point 2 to 3 feet (60 to 90 cm) below the underlying seam. A 1/2-inch (13 mm) steel rod, flush-coupled in 5-foot (1.5 m) sections with a 1-inch (2.5 cm) washer at the base, was inserted into the hole. The rod was then fixed in place with enough Portland cement grout to fill the part of the hole below the lower coal seam. The grout was pumped into the hole below the water to ensure proper setting. One-inch (2.5 cm) poly vinyl chlorite (PVC) tubing was then slipped over the rod to reduce the friction between the rod and the No. 11 Seam footwall strata in case of differential movement (Figure 5).

The roof pin was a standard 6-foot (1.8 m) roof bolt. The hole was drilled with a stoper in line with the footwall hole. The roof bolt was grouted in place with a single resin cartridge and left untensioned. This gave a very crude check on bed separation within 5 feet (1.5 m) of the immediate roof.

Hooks were attached to both pins and the distance between them was measured with a steel tape mounted on a constant-tension device. An accuracy of ± 2 mm was possible with this instrument. Four sets of pins were installed in cross-cuts 22, 24, 38 and 40 (Figures 5 and 6).

Load cells

Initially very little was known about the roadway deformation. The possibility that negligible convergence would take place, had to be considered. Therefore, it was thought prudent to include a roof-to-floor pressure measuring device. We decided to use pack-dynamometers with 6-inch (15.2 cm) diameter pistons, mounted on wooden posts. Each dynamometer was fitted with about 3 feet (90 cm) of hydraulic tubing, a pressure gauge of 0 to 3000 or 2000 psi (0 to 21 or 15 MPa) range, and a valve. The dynamometer was set on a wooden post, shimmed with wood against the roof, and preloaded to about 500 psi (3.5 MPa). As a safety precaution each dynamometer was chained to the closest roof bolt. Some problems were encountered with pressure fittings, but these were ultimately resolved. Fourteen load cells were installed (Figures 5 and 6). Readings were taken from the pressure gauges with an accuracy of ± 50 psi (0.3 MPa).

Extensometers

Multi-wire extensometers were used to evaluate the deformation of pillars [4]. The installation procedure involved drilling a 3-inch (7.6 cm) diameter hole to the centre of the pillar, if possible, and successively placing wire-anchors and casing in the hole. A collar station on a 5-foot (1.5 m) section of steel pipe was then grouted into the hole. The anchors were of a wedge design and were fixed in place by a small hydraulic ram attached to the anchor by shear pins. A diameter survey was taken in each borehole before the location of the anchors was decided. This procedure eliminated the possibility of trying to set an anchor in a caved portion of the hole. The casing between the anchors consisted of 2-inch (5 cm) PVC tubing and was intended to keep the coal from caving into the borehole; this proved to be very successful. A Newcastle Mk II Extensometer was used to measure the wire lengths. Hedley [4] determined an accuracy of ± 0.001 inch (0.025 mm) for this instrument; this is much better than required by the large movements encountered - greater than 15 cm (6 inches). Four extensometer installations were made in cross-cuts 10, 10A, 22 and 38; those in cross-cuts 10A and 22 could only be installed to 18 feet (5.5 m) because the boreholes were squeezed shut beyond this point.

Strata deformation holes

Interbedded sandstones, siltstones, shale and coal comprise the 340 feet (104 m) of strata lying between No. 11 and No. 4 Seams (Figure 2). Any interaction of workings in one seam on those in the other must be reflected in this rock mass. An attempt to obtain some information about the behaviour of the strata had to be made. Wire extensometers were considered to be inapplicable in this case because the number of wires possible was too limited; and the depth was thought to be excessive. A new system was devised where metal rings separated by plastic tubing were grouted into a borehole; their location could then be picked up with a metal detector lowered down the tubing. Deformation parallel to the borehole could then be measured, or the depth to oblique strata movement could be determined.

The installation procedure involved drilling a 3-inch (76 mm) hole from No. 11 Seam down to within about 40 feet (12 m) of No. 4 Seam, inserting 10-foot (3 m) sections of 0.75-inch (19 mm) PVC tubing joined by brass couplings, to the bottom of the hole, and grouting the tubing into the hole. The grout had to be pumpable, non-shrinking and of low tensile strength.

The original measuring unit was a metal-detector probe suspended from a survey chain and connected to a frequency counter by an electrical cable. The accuracy of this system was about ± 0.03 feet (9 mm). However, the cable reel, frequency counter, and collar station were heavy and awkward; therefore a new unit was designed which operated as a down-hole radio transmitter. It was still suspended from a survey chain, which doubled as an antenna, and a small receiver near the collar was used to pick up the signal.

Five installations were made in 1974, the locations are shown in Figures 5 and 6.

RESULTS AND ANALYSIS

DEFORMATION DATA

The instrumentation described above was installed over a period of time: some during initial development and others as needed to fill in the overall network. Mining in No. 4 Seam continued throughout the development of the beltway. The following mining pattern in No. 4 Seam should be kept in mind when considering the data obtained (see Figure 6): the area inbye cross-cut 45 is virgin coal; the area under cross-cuts 45 to 39 had been depillared before the beltway was developed; up-dip from the area under cross-cuts 39 to 32 depillaring was in progress during beltway developments; the area under cross-cut 32 to 29 was left as a safety pillar for a low-angle thrust fault; and only the area outbye cross-cut 29 was progressively undermined after instrumentation had been installed.

Readings on the instruments were taken predominantly by McIntyre staff: levels and strata deformation holes - on a monthly basis and the other instruments - weekly. The roof of No. 11 Seam is used as the reference horizon for most of the data; bed separation in the immediate roof is insignificant and can be disregarded in respect to levels and convergence.

Levelling profiles

The changes in elevation along No. 2 Entry are shown in Figure 7; for clarity only some of the survey results are shown. The baseline represents the first survey of each station; any deformation prior to this is, of course, an unknown quantity. The area between cross-cuts 39 and 45 may well have subsided prior to the beltway development.

Three separate areas of subsidence can be seen on Figure 7, separated by areas of reduced movement. Subsidence of up to 1 foot (30 cm) occurred between cross-cuts 33 and 36; where the extracted width (200 to 300 feet, 60 to 90 m) is probably subcritical. Mining in No. 4 Seam, under this area was carried out up-dip of No. 2 Entry. The second area extends from cross-cuts 17 to 29; it was progressively undermined to an extraction width of 500 to 750 feet (150 to 230 m). Subsidence of over 1 foot (30 cm) was measured in April 1975 and continued to a maximum of 3.5 feet (110 cm) by August 1976. An attempt to relate the initiation of subsidence in No. 11 Seam to an average line of caving in No. 4

Seam was made in this area. The resulting angles of draw, measured from the vertical, varied from 65° to 78°, with an average of 74°. This is a very high angle of draw compared to published data (e.g. [5], p. 92). A third area extends from cross-cut 13 to 4, where movement occurred prior to mining underneath. A block of No. 4 Seam, 200 by 300 feet (60 by 90 m), 300 feet (90 m) from the beltway was mined out of phase with the general retreat pattern. This mining seems to have initiated the subsidence of 1 foot (30 cm) in the area in November 1975; by August 1976 subsidence of 4.5 feet (140 cm) had taken place.

The intervening areas of lesser subsidence have quite different origins: between cross-cuts 33 and 29 a massive safety pillar was left in No. 4 Seam; between cross-cuts 13 and 17 a double abutment was created by the mining pattern in No. 4 Seam a large block of coal had to be left in No. 4 Seam, in this area, due to excessive strata pressure.

Convergence rods

The massive sandstone roof in No. 11 Seam does not exhibit bed separation in the immediate roof; convergence, therefore, is a measure of floor heave. The deformation, observed underground consisted of gradually widening floor-cracks oriented randomly; this was followed by large scale heaving, centred about the cracks, and resulted in mound-like-structures along the floor. The readings obtained from the convergence rods were plotted weekly on 'cumulative convergence curves' for each station. Figure 8-A shows one of these curves for cross-cut 22: initially a low and steady convergence, followed by rapid convergence and then a slow levelling-off to a low slope. This pattern of convergence is present, to some degree, at all stations. In order to accentuate the time of rapid convergence for correlation between stations, the rate of convergence was plotted against time (Figure 8-B); from these curves an isometric diagram was constructed to show station location and change in the rate of convergence with time (Figure 9).

Floor heave, as measured in No. 11 Seam shows two distinct types of behaviour: movement at very low rates for long periods of time (e.g. cross-cuts 36, 32, 14, 12, 10 - Figure 9), and movement rapidly building up to very high rates but lasting only a relatively short period of time. Floor heave at a rate of about 1 mm per day (0.04 inch/day) was usually measured in those areas unaffected by other mining operations both before and after pillaring operations in No. 4 Seam. This type of deformation is considered to be a creep phenomenon. The high rates of convergence (greater than 0.25 cm/day, or 0.1 inch/day), so pronounced in Figure 9, represent the reaction of the floor to induced loading of the system by mining operations in No. 4 Seam. Convergence-velocity peaks can, therefore, be considered as periods of increased load on the pillars surrounding the individual convergence rods. The area from cross-cut 29 to 33 showed high rates of convergence during initial mining; located over the safety pillar in No. 4 Seam, and under the thickest overburden (1300 feet, 400 m) in No. 11 Seam, this area was under active loading at the time of mining. The area out to the portals, cross-cuts 28 to 2, shows a sequential time-shift in the appearance of the first convergence-velocity peaks. The timing coincides with initiation of subsidence. This indicates that the front abutment of the pillaring operation lies at an angle of about + 20° to 25° (from the horizontal) ahead of the extraction line.

The rate of convergence drops rapidly during active subsidence, and may at times reach a state of divergence for short periods. Overall, however, convergence continues at a low rate throughout the unloading cycle. Secondary peaks that appear on Figure 9 are probably related to crushing of remnant pillars left in the pillared area, and due to the pillaring pattern which did not follow a straight extraction line.

The magnitude of convergence varies considerably; the maximum recorded on the rods was 120 cm (47 inches) at cross-cut 16. This figure, however, is misleading because in some roadways, where no convergence rods were located, floor heave exceeded 6 feet (180 cm) and almost closed the opening.

Roof-to-floor pins

The readings obtained for the distance between the pins was plotted on cumulative convergence curves, similarly to the convergence rod data. The results, however, were quite different. The overall amount of displacement was much smaller between the pins than for the convergence rods - approximate ratio of 1:10. The pins also gave earlier indications of both the loading and unloading phases of the deformation. The comparison between measurements from pins and rods is shown in Figure 10.

FIGURE 10: Comparison of measurements from convergence rods and roof-to-floor pins.

Event	Pins	Convergence rod
Initiation of major convergence (2 sites)	t_i	1 to 2 months after t_i
Highest rate of convergence	same time	same time
Maximum convergence	3 cm	41.4 cm
Start of divergence	t_d	1 to 2 months after t_d, as a decrease in the rate of convergence
Maximum divergence	4.4 cm	0.2 cm

Most of the floor heave, therefore, is caused by thickening of the strata above the floor of the underlying coal seam. Both stations that were undermined (cross-cuts 22 and 24) indicate a new loading phase coincident with the end of the subsidence cycle.

Load cells

The load cells were not very effective. Although peak loads coincided generally with the loading phase as indicated by the convergence rods, the breakup of the floor during floor heave resulted in rather erratic pressure readings. It was not uncommon to see a load cell on its post sitting in a hollow with the floor heaved up about 2 feet (60 cm), within 6 feet (2 m) of the post.

Extensometers

The data obtained from the extensometers indicate that pillar deformation is contemporaneous with floor deformation. All extensometers except cross-cut 38 were undermined after installation. In each of these cases, the peak pillar-expansion rate was reached at the same time as the peak rate of convergence. The outer 10 feet (3 m) of each pillar accounted for about 70% of the expansion measured.

The pillar at cross-cut 10, 100 feet by 80 feet (30 m by 24 m) had a five-wire extensometer installed along its long axis. The measuring intervals, bracketed by the collar station and the anchors were as follows:

interval 1	5 to 10 feet (1.5 to 3 m)
interval 2	10 to 20 feet (3 to 6 m)
interval 3	20 to 30 feet (6 to 9 m)
interval 4	30 to 40 feet (9 to 12 m)
interval 5	40 to 50 feet (12 to 15 m),

where all measurements are taken from the pillar edge. During the initial 498 days interval 1 expanded 8.7 cm (3.4 inches), interval 2 - 2.3 cm (0.9 inch) and interval 3 - 0.5 cm (0.2 inch), with no expansion in the other two intervals. The rate of convergence started to rise abruptly at 500 days; over the next 196 days the expansion was as follows:

interval 1 - 22.3 cm (8.8 inches)
interval 2 - 6.2 cm (2.4 inches)
interval 3 - 5.1 cm (2.0 inches),

with intervals 4 and 5 still stable. The largest increase in strain, by a factor of 10, took place in interval 3. This indicates that a progressive failure of the pillar was initiated by the abutment load. Beyond this time, the rates of expansion dropped as subsidence started in this area. The loading cycle is not completed at the time of writing; therefore, we cannot even guess what the strain curves will be when overburden loads are again applied to this pillar.

Strata deformation holes

The data obtained from the five holes showed that no measureable bed separation occurred in any of the holes. Instead, four of the holes exhibited successive blockages to the passage of the probe. Whether the holes were sheared off or deflected, could not be determined in most cases; but on two occasions a weight, shorter and of smaller diameter than the probe, could be lowered past the blockage. Only the hole in cross-cut 42, drilled after pillaring in No. 4 Seam had been completed in that area, remained open. The other four holes initially were all blocked between 196 to 207 feet (59.7 to 63.1 m) below No. 11 Seam. This is a zone of interbedded mudstones, sandstones and silts overlying a massive sandstone/siltstone unit (Figure 2). Successive blockages in the holes seemed to follow this pattern of shear movement above massive, competent units. It is curious that no blockages occurred in No. 10 Coal Seam; possibly shear movement was distributed over a sufficiently wide zone to reduce the amount of flexure on the tubing.

Although the amount of information obtained from the strata deformation holes was limited, it did show that bed separation in the rock mass between No. 11 and No. 4 Seams was negligible. The mode of deformation was probably by flexural-slip folding hinged over the abutments.

SUBSIDENCE RELATED TO NO. 4 SEAM EXTRACTION

The major problem in relating subsidence in No. 11 Seam to extraction of No. 4 Seam was to determine the location of a break or cave line. Room and pillar mining requires a number of separate mining sections, in each section pillars have to be cut, then split and finally extracted. Roof condition and the amount of floor coal recovered have a direct bearing on the retreat rate. To overcome this problem, the No. 4 Seam workings were arbitrarily divided into a number of narrow blocks. Each was centred under the intersection of an instrumented cross-cut with the beltway, and extended 600 feet (183 m) to either side of the beltway, and halfway to the next instrument station along the belt.

Mining in No. 4 Seam was then expressed as the percentage extraction by area, in each block. Since the change in roof elevation was known from the levelling data, the ratio of extraction to change in elevation was investigated in relation to time. Two subsiding areas were considered: cross-cuts 2 to 13 and cross-cuts 17 to 29. The following ratios were calculated for each mining block:

$$R_d = \frac{\text{percent extraction during development}}{\Delta h}, \text{ at time } t_o$$

$$R = \frac{\text{cumulative percent extraction during pillaring}}{\Delta h}, \text{ at time } t_i$$

where Δh - the change in roof elevation of No. 11 Seam in feet,

t_o - the time when pillar extraction started in a given block,

and t_i - time in days after t_o.

Pillar extraction, in this case, included new roadways, pillar splits, and actual pillar extraction subsequent to the original development in No. 4 Seam.

The distribution of R against time should tend towards infinity when Δh is 0, and reach a constant minimum value when t_i is very large. This relationship between R and t_i, therefore, can be approximated by a hyperbolic function of the form

$$R = \frac{a}{t_i} \qquad (1)$$

where 'a' is a constant.

This curve is asymptotic to both the abscissa and the ordinate. However, Δh does not equal 0 at t_o, since subsidence is initiated prior to actual mining in a given block; and the minimum R values must be much larger than one. These differences can be incorporated by shifting the curve in relation to the axes; this requires two additional constants b and c:

$$R = \frac{a}{t_i + b} + c \tag{2}$$

A best-fit curve for our data was obtained by using the following linear form of equation (2)

$$R = a\,x + c \tag{3}$$

where $x = \frac{1}{t_i + b}$,

and reiterating a linear regression for various values of b, to maximize the correlation coefficient.

For the area between cross-cuts 2 and 13

$$R = \frac{9905}{t_i + 32} + 0.283 \tag{4}$$

with a correlation coefficent of 0.764 where N equals 20; and for the area between cross-cuts 17 and 28

$$R = \frac{11767}{t_i + 40} - 1.6 \qquad (5)$$

with a correlation coefficient of 0.922 where N equals 24. Although the numerical values for a, b and c are slightly different, for our range of data the curves are nearly identical. All the data from the two subsiding areas was, therefore, combined and

$$R = \frac{10455}{t_i + 35} + 1.31 \qquad (6)$$

with a correlation coefficient of 0.866 where N equals 44. Figure 11 is a plot of equation (6) along with the data points for the two subsiding areas.

Some of the factors contributing to the scatter of the data are listed below:

- the arbitrarily chosen dimensions of the mining blocks in No. 4 Seam may not include the total contributory area,
- only the front abutment is considered in equation (2),
- extraction was taken as a percentage of the area opened up by mining and does not account for the variable amount of floor-coal recovered during pillar extraction,

- the variable rate of retreat inherent in the mining system.

Equation (6) gives a best-fit curve for the available data. The constants (a, b and c) offer some interesting implications regarding the interaction between seams. The degree of curvature in the hyperbola is expressed by 'a'; it therefore represents the changing rate of reduction in R with time. Given a constant rate of extraction, 'a' should be a function of strata behaviour to undermining and the thickness of coal mined. At time t_o subsidence had already been initiated above the mining block; 'b' is probably related to this lead time, and is dependant on the angle of draw and the rate of extraction. The asymptotic R value (c) represents the ultimate ratio of percent extraction to subsidence. The value in equation (6), of 1.31, is much too low, probably by one order of magnitude. This discrepancy is caused by the relatively short observation time for our data. More data on seam interaction will be required to evaluate this distribution.

GENERAL OBSERVATIONS

Development of the beltway entries proceeded on schedule to completion in February 1975. Some of the operational problems, arising out of the strata deformation are discussed below.

Initially the entries were driven on a spacing of 80 feet (24 m) and 100 feet (30 m) between centrelines. But early pillar deformation, mostly rib sloughing around cross-cut 10 in a 60-foot by 60-foot (18 m by 18 m) pillar, resulted in management widening this spacing to 120 feet (37 m). Once the beltway had been developed beyond the No. 4 Seam workings, the spacing was again reduced to 80 feet (24 m).

Pillar deformation varied greatly with time and different locations. Inbye cross-cut 26 pillar deformation was noted shortly after cutting the coal. The coal rib moved into the opening along finite bedding planes in the seam, leaving a stepped surface. These movements were small, initially in the order of 1 to 2 inches (2.5 to 5 cm). However, around cross-cut 30, up to 18 inches (46 cm) of movement was measured along the low-side rib, within a month after mining. Past cross-cut 34 rib movement was minimal after mining, and remained at that level. The progress of pillaring operations in No. 4 Seam brought about a renewed pillar expansion in No. 11 Seam. Rib posts were either pushed out, where little load had come onto the posts; or broken where lagging was pushed against the posts by the coal rib. Re-timbering along the beltway and the supply road had to be carried out repeatedly.

Floor heave was encountered, during development, between cross-cuts 28 to 34. This movement only persisted for about 4 months, and the total convergence in the beltway and the supply road was not enough to interfere with the mining operation. However in February 1975, floor heave started outbye cross-cut 28 and progressed along the entries towards the portals. Although one to two feet (30 to 60 cm) of clearance were left under the suspended belt structure on the high side, this space soon disappeared. Selective hand-brushing of the floor kept the belt in operation until the end of the year; but in January 1976 it was necessary to shut down the belt. The belt structure was removed from cross-cut 11 to 28 and 2.5 to 4 feet (90 to 120 cm) of floor strata were brushed. When this section had been completed floor heave had progressed to cross-cut 5. This section, therefore, was also brushed before the belt was put back into operation in May 1976. The convergence rod data gave an excellent indication where floor heave was about to start, and even more important, when floor heave was nearly completed. It should be noted here that floor heave did not affect rib-posts or wooden cribs set at intersections.

The roof conditions in No. 11 Seam were good to excellent in terms of the initial development. Roof falls occurred in three areas where roof bolts had been used as the sole method of support. In December 1974 a 40-foot (12 m) section fell to a height of 6 feet (1.8 m), between cross-cuts 37 and 38 in the return airway - No. 4 Entry. This fall was not cleaned up. In May 1975 three shallow roof falls (3 feet, 0.9 m) occurred between cross-cuts 23 and 25 along the supply road - No. 2 Entry. An attempt was made to hold the roof with wooden sets, but these were knocked out by a subsequent fall. Steel arches were finally used to hold the roof in this section. The third fall, in July 1976, has been the only one in the beltway. It comprised a 40-foot (12 m) section to a height of 6 feet (1.8 m) straddling the intersection at cross-cut 43. The roof was re-bolted, and steel girders and timber were installed for support. In all three areas, the roof strata seemed to be more thinly bedded than the usual massive sandstone encountered in the drill holes.

During abutment loading, when both pillar and floor deformation were taking place, no changes in the roof were noted. But during the late stages of subsidence random cracks opened up in the roof. In some localities it seemed prudent to put up steel girders on wooden cribs over the belt structure, but no weight came onto these girders. It would appear that the cracks in the roof are not inducing bed separations in the sandstone.

Overall the instrumentation in No. 11 Seam gave adequate warning of the deformation in the roadways. The cycle of rib sloughing, floor heave and finally roof cracks, progressed along the entries from cross-cut 28 to 4. Since mining in No. 4 Seam is not yet completed (September 1976) the final effects of undercutting the beltway are not entirely known.

CONCLUSIONS

Multi-seam mining in the Rocky Mountains and Foothills has not been documented in the past. The joint project, between McIntyre Mines Ltd. and the CANMET Mining Research Laboratories, was initiated to study the rare occurrence of undermining an underground beltway. Since the beltway was developed while pillar extraction was in progress in the lower No. 4 Seam, instrumentation was installed over virgin coal, extracted and caved workings, and developed coal that was later mined out. It was, therefore, possible to isolate the strata behaviour solely due to undermining. The following discussion refers only to that part of the beltway progressively undermined after instrumentation (cross-cuts 2 to 28; area E, Figure 6).

The beltway entries were developed in No. 11 Seam in essentially stable ground. There was an immediate reaction to this entry development; a high rate of convergence in the form of floor heave was recorded. Near the 100-foot and 80-foot (30 m and 24 m) pillars, this initial convergence lasted a very short time, whereas it persisted longer near the 60-foot (18 m) pillars. This was followed, in both cases, by a period of steady-state convergence, at less than 1 mm per day (0.04 inch per day), primarily due to creep in the thin coal seam underlying No. 11 Seam. No change in the roof elevations could be detected at this time.

Pillar extraction in No. 4 Seam induced abutment effects in No. 11 Seam at an angle greater than 60° to the vertical ahead of the cave line. First, the roof-to-floor pins indicated a slight increase in convergence; second, the convergence rods showed a rapid increase in the rate of convergence; simultaneously the extensometers indicated increased pillar expansion, and the first subsidence effects of less than 0.25 feet (7.5 cm) were measured. This is the loading phase of seam interaction. The most pronounced effect is the massive floor heave resulting from coal, in the floor, being squeezed out, from under the pillar, towards the roadways and lifting the floor strata.

The loading phase was followed by major subsidence as pillar extraction took place directly below a given point along the beltway. Roof elevations dropped; roof-to-floor pins showed differential subsidence between roof and floor, with an overall trend towards divergence; and the convergence rods indicated a marked reduction in the rate of convergence, with few instances of divergence. Overall subsidence, in the order of 3 to 5 feet (1 to 1.5 m), occurred over a period of 200 days.

The final phase of interaction is a return to a relatively steady state. Subsidence is minimal; and the convergence rods and pins show a steady, very low rate of convergence. This pattern of deformation has been documented for the No. 11 Seam beltway. It should be noted, however, that the pillar extraction pattern used in No. 4 Seam created a double abutment between cross-cuts 13 and 17 (see Figure 7). This area of 11 Seam will have to be monitored very carefully, in order to determine strata behaviour in this situation.

The documentation of strata deformation along the beltway, has identified, for the mine operator, the support behaviour, and the effects of pillar design and pillar extraction methods. Specifically for No. 11 Seam/No. 4 Seam interaction the results have been quantified; this has been of practical assistance to the preventive maintainance program. The outcome of this study has been to further emphasize that detailed planning and operational control is required prior to and during multi-seam mining.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the facilities provided by both McIntyre Mines Ltd. and CANMET. The cooperation received from the production officials at the mine, the engineering, and the technical staff were essential to the outcome of this project.

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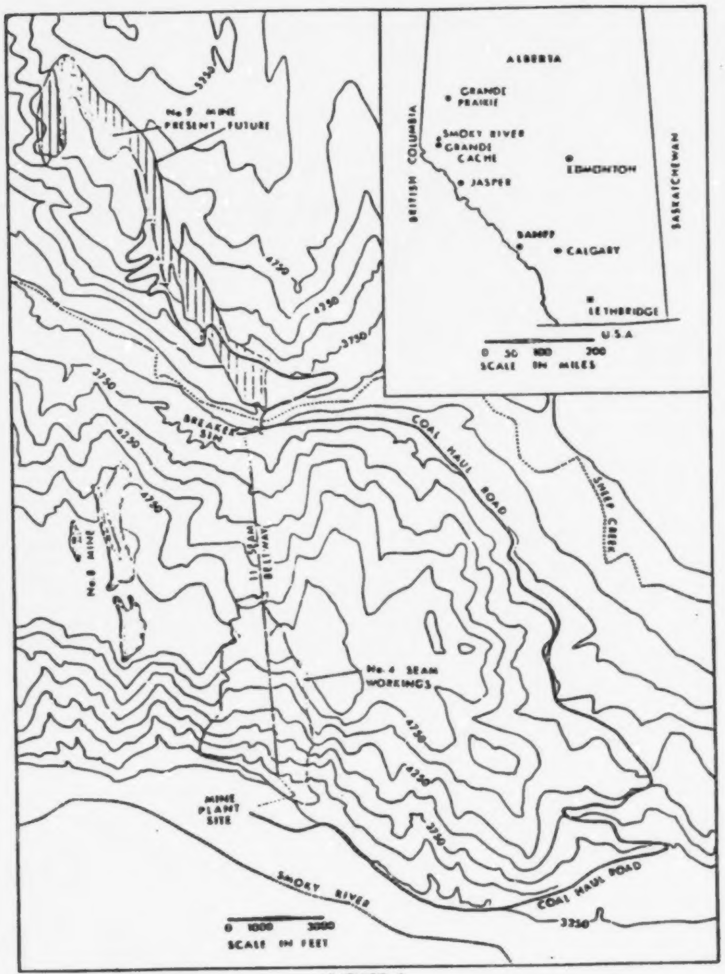

ALBERTA
GRANDE PRAIRIE
SMOKY RIVER
GRANDE CACHE
EDMONTON
JASPER
BANFF
CALGARY
LETHBRIDGE
BRITISH COLUMBIA
SASKATCHEWAN
U.S.A.
0 50 100 200
SCALE IN MILES
No. 9 MINE
PRESENT FUTURE
3250
4750
4250
3750
3750
BREAKER BIN
COAL HAUL ROAD
4250
4750
No. 8 MINE
11 SEAM BELTWAY
SHEEP CREEK
No. 4 SEAM WORKINGS
4750
4250
3750
MINE PLANT SITE
SMOKY RIVER
COAL HAUL ROAD
3250
0 1000 3000
SCALE IN FEET

FIGURE 1

Figure 1 General Map of the McIntyre Mines Ltd. Smoky River Operations, showing the No. 9 open pit mine, the coal haulage road, the beltway and the No. 4 Seam workings; the contour interval is 250 feet (76.2 m).

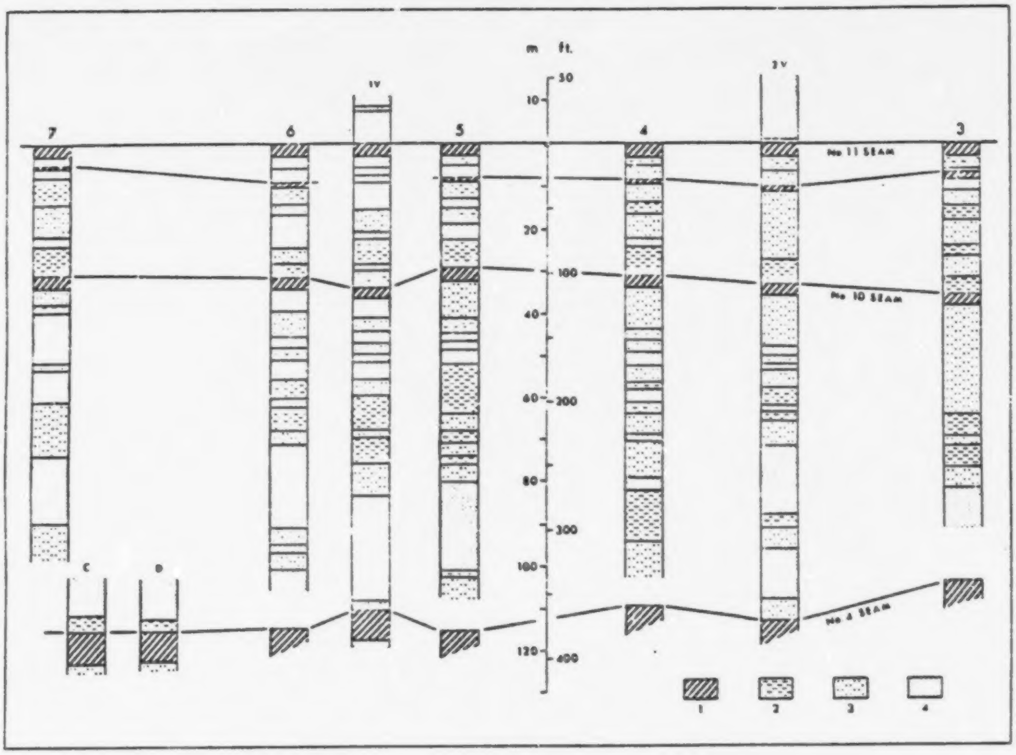

m ft.
7
6
1V
5
4
2V
3
C
D
No 11 SEAM
No 10 SEAM
No 4 SEAM
10
20
40
60
80
100
120
50
100
200
300
400
1
2
3
4

FIGURE 2

Figure 2 Stratigraphic Correlation Chart for the section between No. 11 and No. 4 Seams. Datum is the roof of No. 11 Seam (Legend 1. coal, 2. shale/mudstone, 3. siltstone, 4. sandstone).

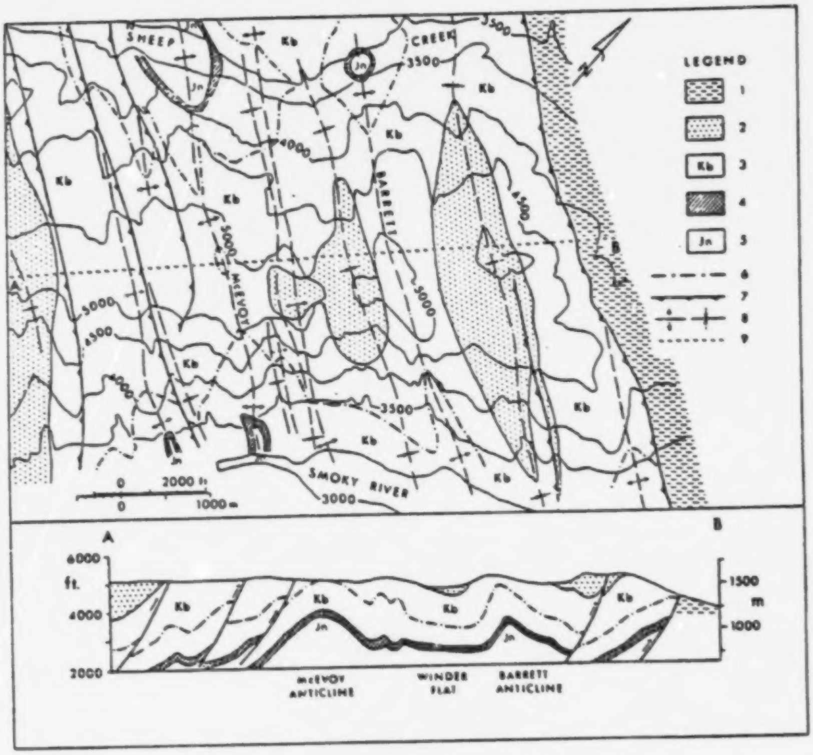
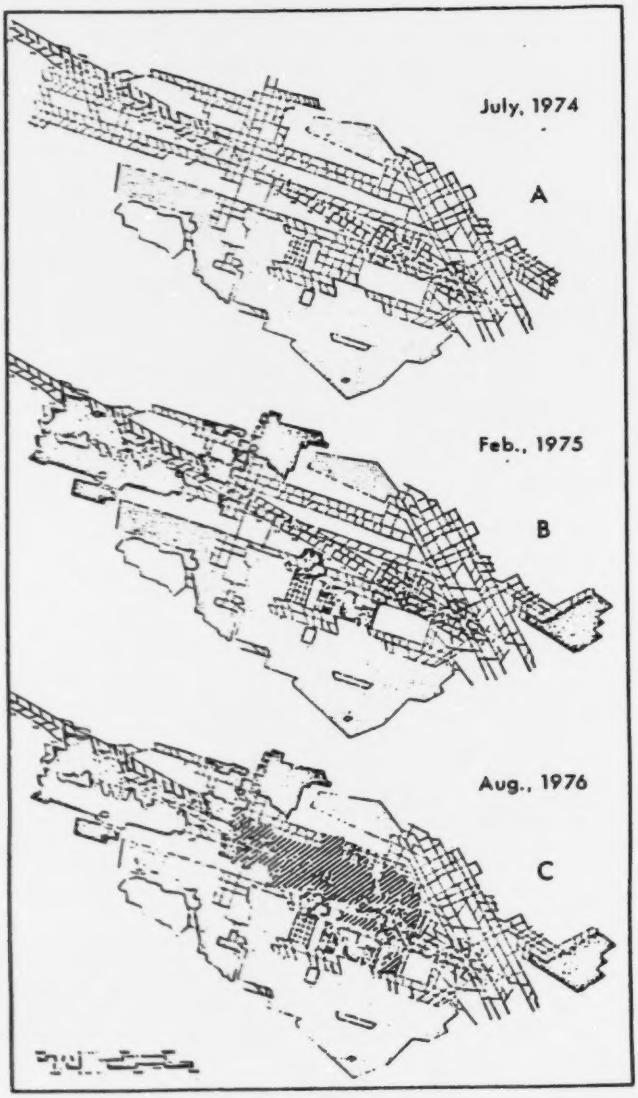

SHEEP
CREEK
3500
Kb
Jn
4000
BARRETT
McEVOY
5000
4500
A
B
SMOKY RIVER
3000
0 2000 ft
0 1000 m
LEGEND
1
2
Kb 3
4
Jn 5
6
7
8
9
6000 ft.
4000
2000
1500 m
1000
McEVOY ANTICLINE
WINDER FLAT
BARRETT ANTICLINE

FIGURE 3

Figure 3 Geologic Map and Section of the Mine Area, contour interval is 500 feet (152 m). (Legend: Cretaceous, 1. Blackstone Formation; 2. Dunvegan and Shaftesbury Formation; 3. Blairmore Group including the Luscar Formation; 4. Cretaceous/Jurassic Cadomin conglomerate; 5. Jurassic Nikanassin Formation; 6. No. 4 Seam; 7. Thrust faults; 8. Anticline and Syncline; 9. Structure Section (A-B).



July, 1974
A
Feb., 1975
B
Aug., 1976
C

FIGURE 4

Figure 4 Pillar Extraction Plans for No. 4 Seam Workings, A - July 1974, B - February 1975, C - August 1976.

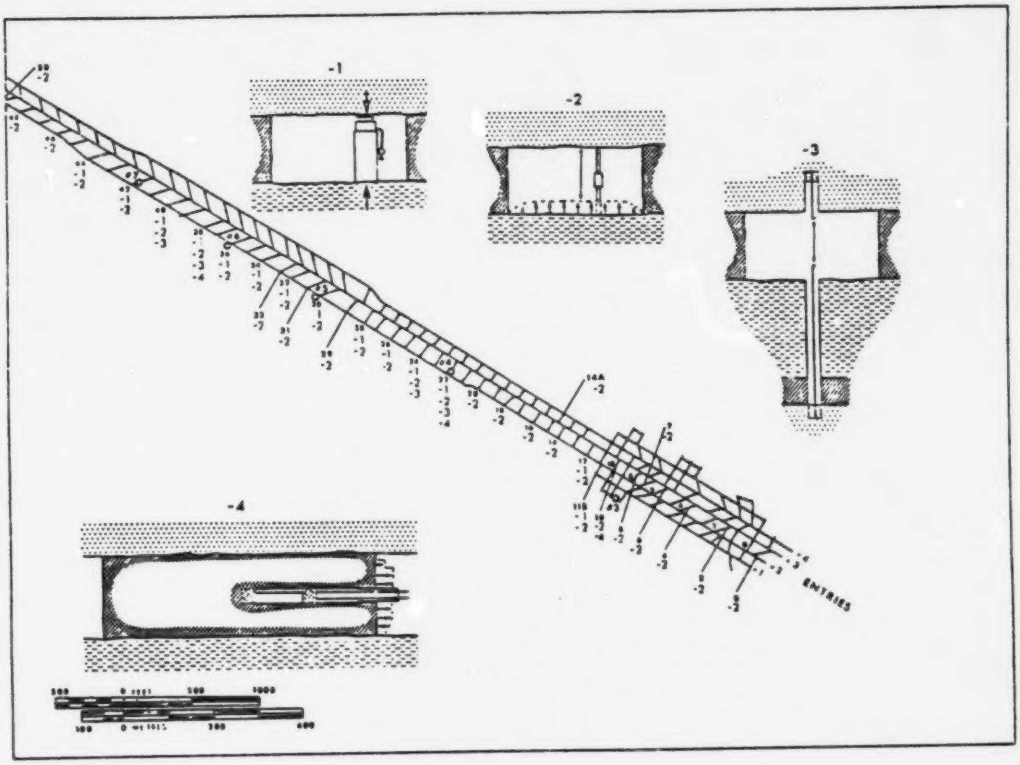


FIGURE 5

Figure 5 No. 11 Seam Instrumentation Plan showing cross-cut and entry numbers and types of instruments: -1 load cells, -2 convergence roads, -3 roof-to-floor pins, -4 multi-wire, pillar extensometers.

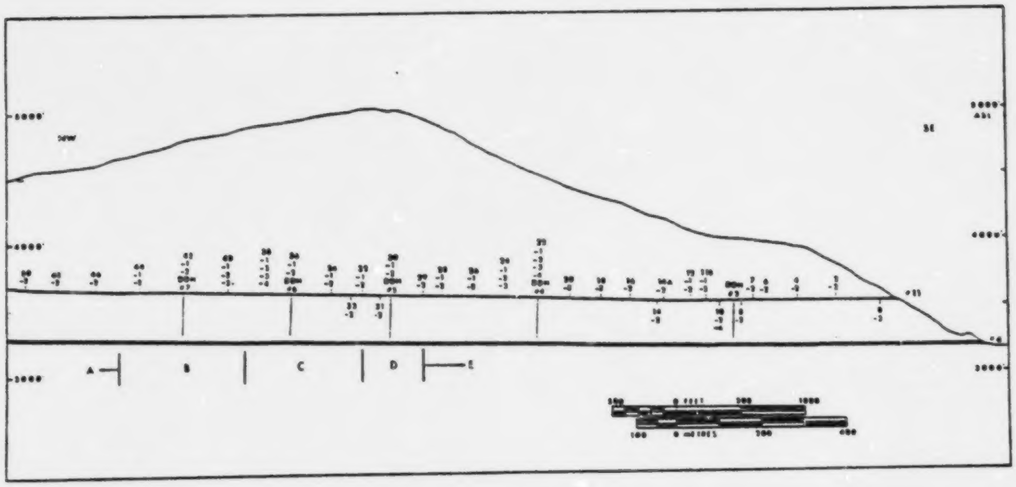


FIGURE 6

Figure 6 Section along Beltway, showing instrumentation and cross-cut numbers in No. 11 Seam, strata deformation holes, and location of No. 4 Seam; A - virgin coal, B - pillar extraction prior to beltway development, C - pillar extraction in progress during beltway drivage, D - safety pillar, E - progressively undermined after instrumentation was installed.

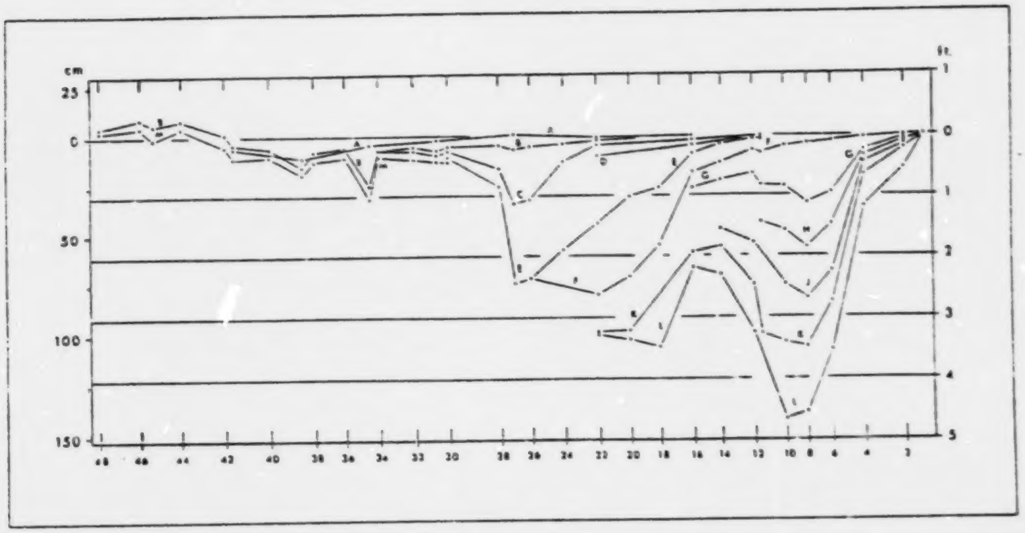


FIGURE 7

Figure 7 Beltway Subsidence Profile; selected survey lines, only, are shown for clarity.

A - Nov. 13, 1974; B - Feb. 14, 1975; C - Apr. 9, 1975;

D - May 28, 1975; E - July 30, 1975; F - Sept 19, 1975;

G - Nov. 5, 1975; H - Feb. 3, 1976; J - Mar. 31, 1976;

K - Apr. 29, 1976; L - July 26, 1976; M - Aug. 16, 1976.

Cross-cut locations are shown along the bottom.

FIGURE 8

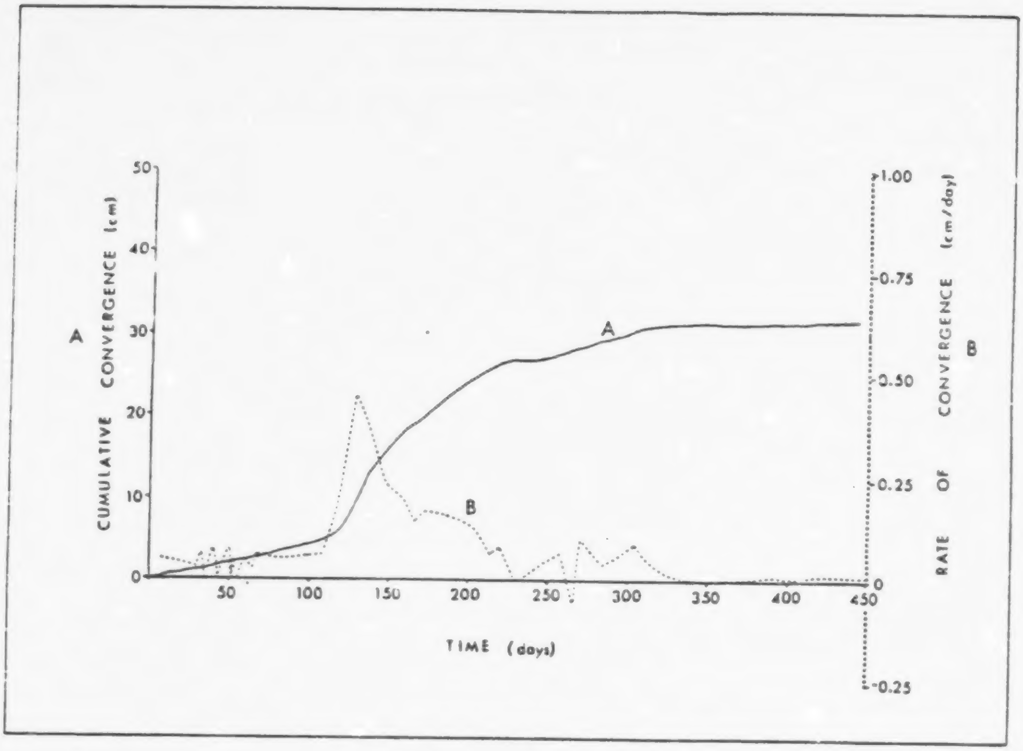


Figure 8 Convergence Data for Cross-cut 22. A - cumulative convergence plotted against time in days, B - the same data expressed as rate of convergence.

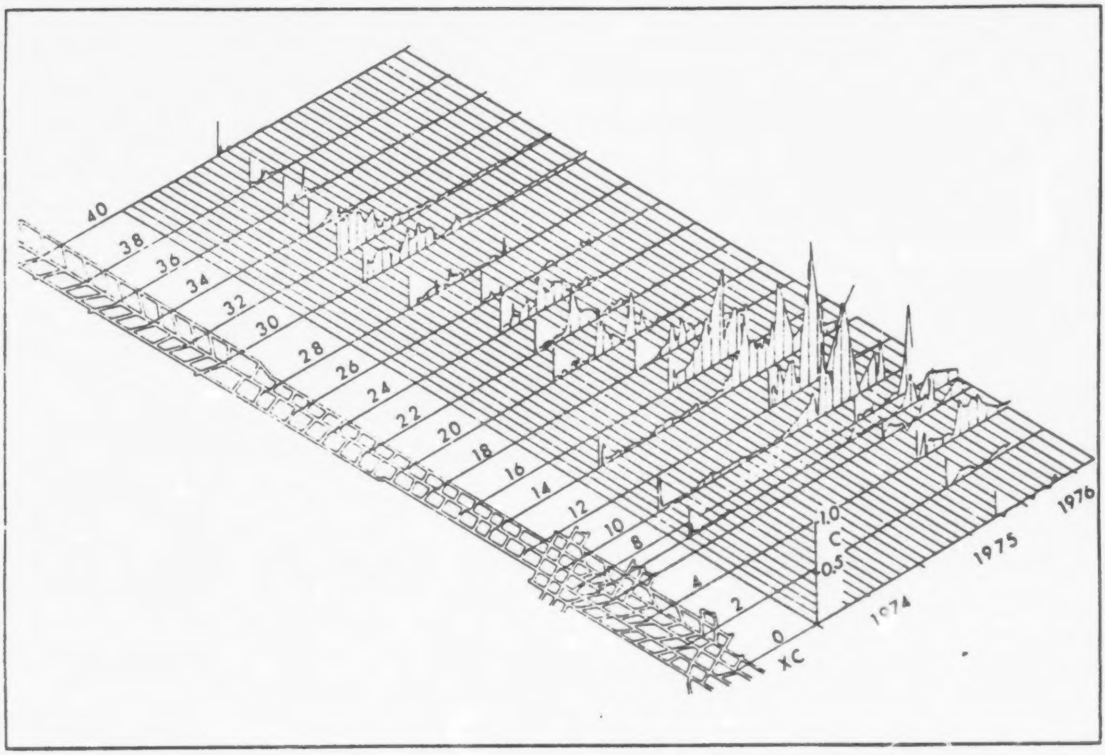


FIGURE 9

Figure 9 Convergence Rate in No. 11 Seam versus Time; XC are cross-cut numbers, C is the rate of convergence in cm/day, and the time is in months.

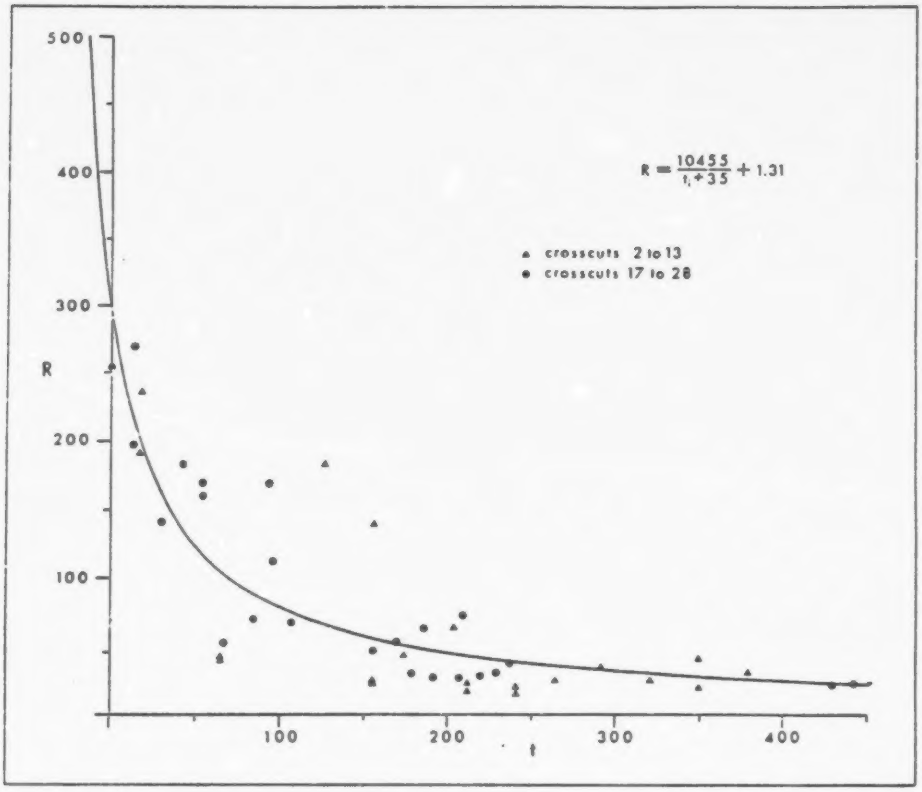


FIGURE 11

Figure 11 Distribution of Ratio R, triangles are data points from cross-cuts 2 to 13 and dots for cross-cuts 17 to 28; see text for explanation.

APPENDIX 4.2

Strata Deformation Above Longwall Faces.

Paper by A N Styler and R K Dunham

STRATA DEFORMATION ABOVE LONGWALL FACES

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INTRODUCTION

The mechanics of strata deformation above longwall faces has attracted the attention of many investigators over the past twenty years. Due to access difficulties very few of these investigations have included detailed measurement of inter-strata deformations at levels above the seam.

In recent years there have been two major investigations to monitor strata deformation above shallow undersea longwalls at Lynemouth Colliery, Northumberland, England, carried out by the University of Newcastle upon Tyne. The initial results of the first investigation have already been published by Hodkin et al (1979).

The present paper presents the final results from both investigations, and compares them with the results of similar studies reported by Malone (1966), Batchelor (1972), Howell et al (1976), Barla and Boshkov (1978), and with predicted values of ground movement obtained using the Subsidence Engineers Handbook (NCB 1975).

OBSERVATIONAL PROGRAMME AT LYNEMOUTH

The instrumentation programmes, to monitor sub-strata movements, were carried out from old room and pillar working in the Main Seam, 85 metres (280 feet) below the sea bed, and 75 metres (245 ft) above the longwall faces in the Brass Thill, Figure 1. The first face to be monitored, K4, was a retreat unit undermining room and pillar workings in the Main Seam only. The second face, K6, was an advancing unit, and undermined workings in both the Main and Yard seams, 12 metres (40 ft) below the Main Seam. Both faces were 180 metres (590 ft) wide with an extracted height of 1.6 metres (5.25 ft).

The general dip of the strata is 1 in 50 to the East, but in the instrumented area there is a shallow syncline with a roughly East-West axis. The lowest point of this syncline is approximately coincident with the line of instrumentation above face K6. One of the instrumented boreholes was cored, from which the uniaxial compressive strength, tensile strength, Youngs Modulus, and rock quality designation (RQD) of the interburden rocks were determined.

K4 Instrumentation

Above K4 face two vertical boreholes, D1 and D2, were drilled down from the Main Seam to within 10 metres (33 ft) of the panel in the Brass Thill Seam. Both holes were above the face centre-line, 19 metres (62 ft) and 76 metres (250 ft) beyond the start line respectively. The well known anchor/strainwire/extensometer technique was used to monitor inter-strata movements in both boreholes. Levels were taken to the mouth of both extensometer holes, to enable absolute movements to be calculated from the strainwire data.

Results of K4 Instrumentation

The results are presented as contours of percentage vertical strain against face advance, and height above the seam, Figures 2 and 3. However, it must be noted that these contours do not represent pure engineering strain, since the movements can consist of bed separation, rock failure, and elastic deformation. The salient features of Figure 2 for borehole D1, are:

(1) There was a delay in movement until the face had advanced 17 metres (56 ft) past the borehole position. This indicates that the strata was arching between the rear pillar and the solid coal in advance of the face, until the total span reached 36 metres (118 ft) when the initial break occured.

(2) Between 45 and 60 metres (148 and 197 ft) above the face, there is an increase in tensile strain. This is probably caused by the formation of cavities due to the beds behaving as beams, and cantilevering about the edge of the rear pillar.

Figure 3 shows the strain contours for borehole D2, and the results are summarized below:

(1) Due to this hole being beyond the influence of the rear pillar the general pattern of the strain contours are completely different than those for borehole D1.

(2) There is a change from compression to tension just behind the face line, after which the spacing of the tensile strain contours increases. This shows that the beds are cantilevering about the solid coal, and then deflecting down into the excavation. The increase in spacing of the contours indicates that the curvature of the strata decreases as it comes into contact with the waste.

K6 Instrumentation

Above the second longwall face, K6, three vertical boreholes were instrumented with a Soil Instruments inclinometer, to monitor lateral movements in two orthogonal directions. Vertical movements were measured from magnetic anchors, attached to the outside of the inclinometer guide tubes, sensed by a reed switch probe. The positions of these boreholes were: above the centre line (D3), half way between the ribside and the face centre line (D4), and 10 metres beyond the ribside over the solid (D5).

Unfortunately due to high concentration of methane flowing out of the boreholes, they had to be sealed off just behind the faceline. This meant that no significant vertical movements were measured, hence only the lateral deformations are presented.

Lateral Deformations Above K6

In order to interpret the measured lateral movements is was necessary to assume that the bottom of the inclinometer tubes have remained stable. Judging from the asymptotic nature of the curves for boreholes D3 and D4, Figures 5 to 8, this assumption is correct.

Due to floor heave just in front of the face causing excessive distortion of these two holes no movements were measured behind the face line. Since the third inclinometer hole, D5, was located over the solid there was not enough movement to damage the lining, however, no significant lateral deformation was measured in this hole, as the face went past, and finished 15 metres (49 ft) away.

Movements parallel to the direction of face advance. The lateral movements measured in both holes parallel to the direction of face advance, Figures 5 and 6, show that the strata movement towards the face increases, as the height above the seam increases. This type of movement is what would be expected from the drawing effect of the subsidence trough, ie subsidence movement occurs first at higher levels.

For borehole D3, Figure 5, at 16 metres (53 ft) in front of the face only the top 32 metres (106 ft) of the hole has moved laterally. This probably indicates where the 'line of draw' intersects the borehole, giving an angle of draw 70° from the horizontal. As the face advances to within 10 metres (33 ft) of D3 the lateral displacement over the length of the hole decreases by over 50%. This was probably due to the bottom of the hole moving towards the face, since at this face position using an angle of draw of 70°, all the borehole is within the zone of draw. Movement trajectories above a longwall face, Figure 4a, as calculated by the National Coal Board, clearly indicate this.

In borehole D4, Figure 6, there was no evidence of the borehole straightening. This is due to the lateral movements being smaller and starting later in this hole, owing to its proximity to the ribside.

Movements parallel to the face line. The movements parallel to the face line for borehole D3 are shown in Figure 7. The maximum horizontal movement of 15 mm (0.6 inches) in this direction is approximately 20% of that measured perpendicular to the face. In fact no movement was expected in this direction, as in theory movements should be symmetrical about the centre of the excavation. This can be clearly seen from Figure 4b showing the movement trajections parallel to the face line.

For borehole D4 the movements parallel to the face are shown in Figure 8. This borehole demonstrates a slight tilt towards the ribside when the hole is 10 metres (33 ft) ahead of the face. As the face advances to within 3 metres (10 ft), the bottom half of the hole bends further towards the ribside, whilst the top of the hole bends towards the centre-line. It can be seen that the displacement profile is no longer asymptotic towards the vertical, possibly implying that the bottom of the hole has moved.

Conclusions from lateral deformations. The lateral movements can be compared with measurements of permeability taken by Neate (1979) above K6 face. The results he obtained concerning the position of the onset of change in permeability, and peak permeability are shown in Figure 9. It can be seen that the peak permeabilities are occuring before any lateral movement was recorded. Somewhat surprisingly this seems to indicate that there is very little correlation between permeability and lateral movement.

A summary of the conclusions that can be drawn from these measurements of lateral movement are:

(1) There was no correlation between lateral movement and geology.
(2) The general trend of movements is towards the centre of the excavation.
(3) Ahead of the face the error in the measurement of vertical deformations due to lateral movement is negligible.
(4) There is no apparent correlation between horizontal movement and changes in permeability.

CASE STUDIES

In order to obtain sufficient measurements of vertical strain, over a range of different conditions, it has been necessary to consider case histories of inter-strata movement from the literature. Full details of four other investigations have been obtained, two in Britain, and two in the United States. All measurements have been taken using the strainwire/anchor/extensometer technique, and presented as contours of vertical strain. The site details and results are discussed in the following section.

Whitburn/Wearmouth Collieries, Durham (Malone 1966)

At this site movements above the NW6 face in the Harvey seam at Whitburn Colliery were monitored from an airway 59.8 metres (196 ft) above, in the Hutton seam at Wearmouth Colliery, Figure 10. The NW6 face was a 182 metre (600 ft) wide advancing unit, with an average extracted height of 1.06 metres (3.5 ft), at a depth of 463 metres (1520 ft). Measurements of inter-strata movement were taken from two boreholes, D6 and D7. The positions of these two holes was over the face centre line, and 54 metres (175 ft) from the centre line, respectively.

Whitburn/Wearmouth results. The strain contours for boreholes D6 and D7 are shown in Figures 11 and 12. The important features are summarised below:

(1) There is a zone of compression in front of the face, with the strains decreasing with height above the seam. This compression zone tends to lean back over the goaf, as can clearly be seen at D6, but to a lesser extent towards the ribside at D7. This shows that the strata is cantilevering as a series of separate beams, with the leaning back over the goaf due to the higher beds resting on the span of the lower beams.

(2) There is a reduction in strain above the seam with increasing distance behind the face. This suggests that the goaf began taking load 46 metres (151 ft) behind the face, and had consolidated to almost its maximum after 122 metres (400 ft) to 153 metres (500 ft) advance.

(3) There was a residual tensile strain of between 0.25% and 0.5% in the near seam strata after movement had finished. Since this value is likely to exceed the elastic tensile strain limit of coal measure rocks, it is apparent that there is some residual fracturing and bed separation, to at least 80 metres (262 ft) above the seam. These residual strains indicate that there is a permanent redistribution of stresses onto the abutments; a common cause of interaction effects in multi-seam layouts.

Markham Colliery, North Derbyshire (Batchelor 1972)

In this investigation boreholes were drilled from an airway in the 1st Piper Seam down to L58's face, 44.7 metres (147 ft) below in the Three-Quarter Seam. L58's was 200 metres (656 ft) wide, with an extracted height of 1 metre (3 ft), and lay at a depth of 585 metres (1920 ft). The instrumentation at this site consisted of four vertical boreholes, D8 to D11, the respective positions of which were; 15 metres (49 ft) over the solid, above the rib edge, half way between the ribside and the face centre line, and above the face centre line. As can be seen from Figure 13, there are two other proximate seams. Both of these have been worked in the past and can be considered as long established. This view was confirmed when the Deep Hard goaf was found to be extremely competent when drilled through. The geological section in the instrumented area was obtained from the examination of drill cuttings.

Markham results. The only significant movements recorded in boreholes D8 and D9 were due to floor heave at the instrumentation level, therefore the results from both these holes are not presented. The results for holes D10 and D11 are shown in Figures 14 and 15, and summarized below:

(1) The very high strains between 40 metres (131 ft) and 45 metres (148 ft) above the seam represent floor heave at the instrumentation level. This floor heave has been caused by interaction with the face, since the airway is an old gateroad with solid coal on one side, and goaf on the other.

(2) In borehole D10 there is an increase in tensile strain just over 30 metres (98 ft) above the face, which is probably due to bed separation between the Siltstone and the overlying Mudstone. This bed separation will be due to the bending of the strata about the ribside.

(3) The near seam strains in D11 start to decrease at approximately 25 metres (82 ft) behind the face line, indicating compaction of the goaf. The near seam strains in D10 are much lower, and show no such decrease, indicating that complete closure and full recompaction of the waste does not occur to the same extent towards the ribsides.

(4) It must be noted that there is goaf on one side of the instrumentation level, and coal on the other. The presence of this solid ribside could considerably influence the results obtained,

Hendrix No 22 Mine, Kentucky (Howell et al 1976)

This investigation was carried out above a shortwall mining area of 6 adjacent panels. The faces were 52 metres (170 ft) wide on 82 metres (270 ft) centres, with an extracted height
metres (4 ft). The depth of cover varied
235 metres (770 ft) above panel 1 to 52 m
(170 ft) at panel 5. The results were ob
from a borehole, drilled from the surface.
the centre-line of panel 1, which was the
be mined, and at the edge of the shortwal
After panel 1 was completed the movements
monitored as the other panels were extrac

Hendrix No 22 results. The results
D12 are shown in Figure 16, and can be su
as:

(1) In the first 10 metres (33 ft)
face there is a large tensile zone,
be due to caving of the near seam st

(2) Between 10 and 15 metres (33 an
above the face the strains are compr
owing to rotation of blocks as they
strata falling as large blocks will
by the sandy nature of the shale.

(3) Above this compressive zone the
become tensile again, probably due t
separation at the base of the thick
bed. This indicates that the sandst
bridging over the excavation apparen
behaving as a beam.

(4) These results indicate that the
caving is 10 metres (33 ft) which is
mately 8 times the extracted thickne
zone of fracturing/bed separation extends to the base of the sandstone, 35 metres (115 ft) above the seam.

Somerset Mine No 60 (Barla & Boshkov 1978)

At this site movements were monitore
the surface and the Pittsburgh Seam, at 1
to 130 metres (330 to 430 ft) of cover.
was 183 metres (600 ft) wide, with an ext
height of 1.7 metres (68 inches). Two bo
D13 and D14, both on the face centre line
instrumented. The holes were 213 metres
30 metres (700 and 100 ft) from the start
panel respectively.

Somerset Mine No 60 results. The ge
results for boreholes D13 and D14 (Figure
18) are summarized overleaf:

(1) The strain contours are extremely "layered", clearly indicating a correlation between strata deformation and geology.

(2) There are several zones of compressive strain which will be due to rotation of blocks as the strata cave. This view is supported by the amount of movement measured in the lower anchors of D14 being in excess of the seam thickness.

(3) The results appear to indicate that the height caving extends to approximately 15 metres (50 ft) in D13,and 21 metres (70 ft) in D14. This corresponds to between 8.8 and 12.3 times the seam thickness.

CONCLUSIONS

Movements above the Ribside

In the boreholes located above and near to the ribside, D5 at Lynemouth, D8 and D9 at Markham, no significant vertical movements were measured. This indicates that gateroad deformation is mainly caused by localized effects,as has been measured by Hardman (1980). These movements are primarily due to the transfer of load from above the excavation onto the ribsides, causing an abutment pressure, and due to pack convergence.

Correlation with Geology

There appears to be some correlation between geology and the vertical movements above longwall faces. This can be most clearly seen in boreholes D12 (Hendrix), D13 and D14 (Somerset), where thick beds of Sandstone or Limestone are either caving as blocks, or bridging over the excavation, causing zones of tensile strain. At holes D6 and D7 (Whitburn), D13 and D14 very high tensile strains near the seam level are associated with weak strata as the beds fracture on caving.

Comparison between British and American Contours

The most striking difference between the two sets of contours, is the dome shape in the United Kingdom, and the flat shape in the United States. This can be explained by the behaviour of the strata in the American case histories being dominated by strong/competent beds, whilst in the British examples there were no beds strong enough to have a noticeable effect on the movements above the face. This difference in behaviour is clearly shown by the maximum subsidence in Britain being up to 90% of the extracted thickness, and only 70% in the United States. Another implication of these results is that empirical methods of subsidence prediction, such as the Subsidence Engineers Handbook (1975), cannot be used for both countries, without a more complete understanding of the influence of the different geology.

The behaviour of these strong beds in the American case histories can have serious consequences for the design of pillars between adjacent longwalls. Wilson (1972) has postulated that the commonly used rule for pillar width of 'one-tenth the depth + 15 yards' requires that the caved goaf takes cover load at a distance of 0.3 times the depth, from the abutments. In the case of a strong bed bridging over the excavation the goaf will only be taking the weight of rock below this bed, whilst the rest of the load is transferred onto the pillars. This high loading of the pillars can lead to pillar failure, causing excessive closure of the gateroads.

Height of Caving

There is a large difference in the height of caving between the two countries. In British coalfields a generally accepted value for the height of caving is three to five times the seam thickness. However, the American case histories indicate a caving height of eight to twelve times the seam thickness. This large difference indicates that the stiffer American strata have a much lower bulking factor than the weak near seam strata generally found in Britain.

Strata Behaviour above a Longwall Face

The results obtained from the British case histories indicate that the strata above a longwall face behaves as a series of slumping beams. These beams cantilever about the face line, as is evidenced by the compressive strains in holes D2 (Lynemouth), D6 and D7 (Whitburn). The pivot point of these beams moves over the goaf with increasing height above the seam, hole D6, indicating that there is a tendency to form a dome of fractured rock above the face. As the beams slump they come into contact with the caved material, thus causing goaf consolidation, holes D6, D7, and D11 (Markham).

centre line, and above the face centre line. As can be seen from Figure 13, there are two other proximate seams. Both of these have been worked in the past and can be considered as long established. This view was confirmed when the Deep Hard goaf was found to be extremely competent when drilled through. The geological section in the instrumented area was obtained from the examination of drill cuttings.

Markham results. The only significant movements recorded in boreholes D8 and D9 were due to floor heave at the instrumentation level, therefore the results from both these holes are not presented. The results for holes D10 and D11 are shown in Figures 14 and 15, and summarized below:

(1) The very high strains between 40 metres (131 ft) and 45 metres (148 ft) above the seam represent floor heave at the instrumentation level. This floor heave has been caused by interaction with the face, since the airway is an old gateroad with solid coal on one side, and goaf on the other.

(2) In borehole D10 there is an increase in tensile strain just over 30 metres (98 ft) above the face, which is probably due to bed separation between the Siltstone and the overlying Mudstone. This bed separation will be due to the bending of the strata about the ribside.

(3) The near seam strains in D11 start to decrease at approximately 25 metres (82 ft) behind the face line, indicating compaction of the goaf. The near seam strains in D10 are much lower, and show no such decrease, indicating that complete closure and full recompaction of the waste does not occur to the same extent towards the ribsides.

(4) It must be noted that there is goaf on one side of the instrumentation level, and coal on the other. The presence of this solid ribside could considerably influence the results obtained.

Hendrix No 22 Mine, Kentucky (Howell et al 1976)

This investigation was carried out above a shortwall mining area of 6 adjacent panels. The faces were 52 metres (170 ft) wide on 82 metres (270 ft) centres, with an extracted height of 1.2 metres (4 ft). The depth of cover varied from 235 metres (770 ft) above panel 1 to 52 metres (170 ft) at panel 5. The results were obtained from a borehole, drilled from the surface, above the centre-line of panel 1, which was the first to be mined, and at the edge of the shortwall area. After panel 1 was completed the movements were still monitored as the other panels were extracted.

Hendrix No 22 results. The results of borehole D12 are shown in Figure 16, and can be summarized as:

(1) In the first 10 metres (33 ft) above the face there is a large tensile zone, which will be due to caving of the near seam strata.

(2) Between 10 and 15 metres (33 and 49 ft) above the face the strains are compressive, owing to rotation of blocks as they cave. The strata falling as large blocks will be caused by the sandy nature of the shale.

(3) Above this compressive zone the strains become tensile again, probably due to bed separation at the base of the thick sandstone bed. This indicates that the sandstone is bridging over the excavation apparently behaving as a beam.

(4) These results indicate that the height of caving is 10 metres (33 ft) which is approximately 8 times the extracted thickness. The zone of fracturing/bed separation extends to the base of the sandstone, 35 metres (115 ft) above the seam.

Somerset Mine No 60 (Barla & Boshkov 1978)

At this site movements were monitored between the surface and the Pittsburgh Seam, at 100 metres to 130 metres (330 to 430 ft) of cover. The panel was 183 metres (600 ft) wide, with an extracted height of 1.7 metres (68 inches). Two boreholes, D13 and D14, both on the face centre line were instrumented. The holes were 213 metres and 30 metres (700 and 100 ft) from the start of the panel respectively.

Somerset Mine No 60 results. The generalised results for boreholes D13 and D14 (Figures 17 and 18) are summarized overleaf:

The results of the American studies show a completely different type of behaviour due to the stronger nature of the strata. This more competent strata is less pliable than that in Britain, hence the beds are not able to deform into the excavation to the same extent. This stiffer nature of the strata causes the beds to hang up, and then finally cave as a competent mass.

The results presented demonstrate that the slumping beam concept is only applicable where there are no strong/competent beds. In the cases where there is strong strata, these beds tend to dominate the deformation pattern above a longwall face.

Modelling Deformations above Longwall Faces

These results clearly show that the zone of fractured rock above a longwall face is dependent on the strength of the various strata. In order to model deformations above a face more accurately an area of fractured rock must be included. The extent of this area should be estimated on the basis of whether there are any strong/competent beds in the nether roof.

ACKNOWLEDGEMENTS

We wish to thank the National Coal Board for the financial and practical support for the Lynemouth experiment.

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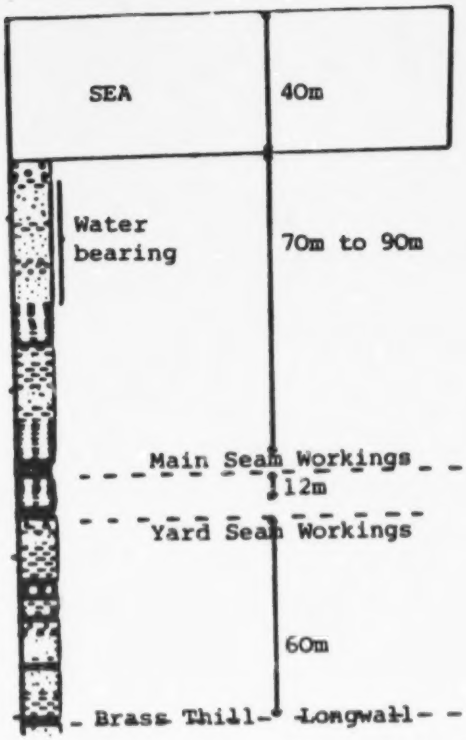
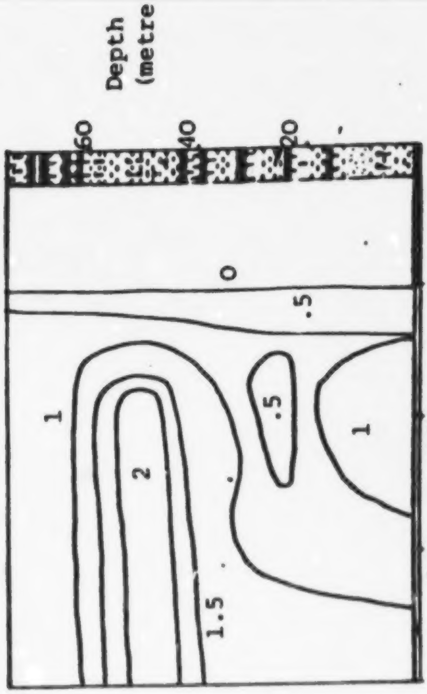

SEA
40m
Water bearing
70m to 90m
Main Seam Workings
12m
Yard Seam Workings
60m
Brass Thill Longwall

Figure 1

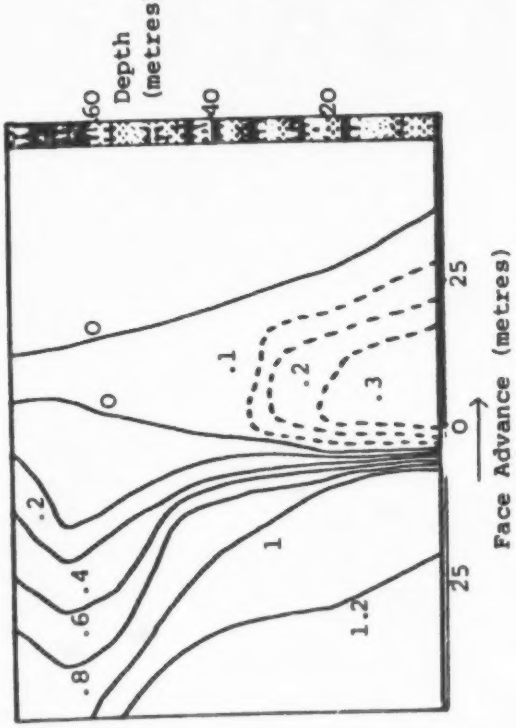
▨ Sandstone — ■ Coal seam — - - - - Compressive strain

▤ Siltstone — ☰ Mudstone — ——— Tensile strain



Borehole D1

Figure 2



Borehole D2

Figure 3

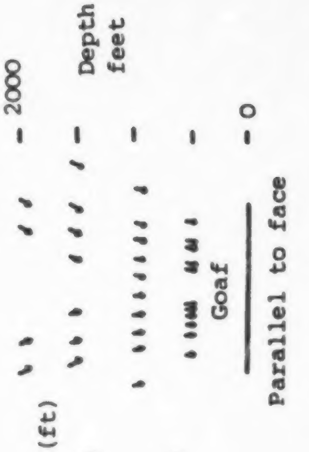


Figure 4b

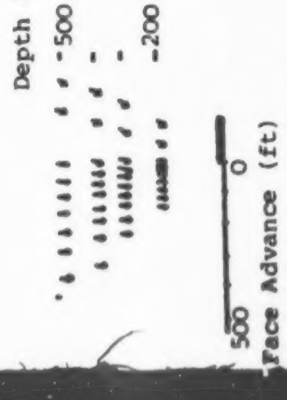
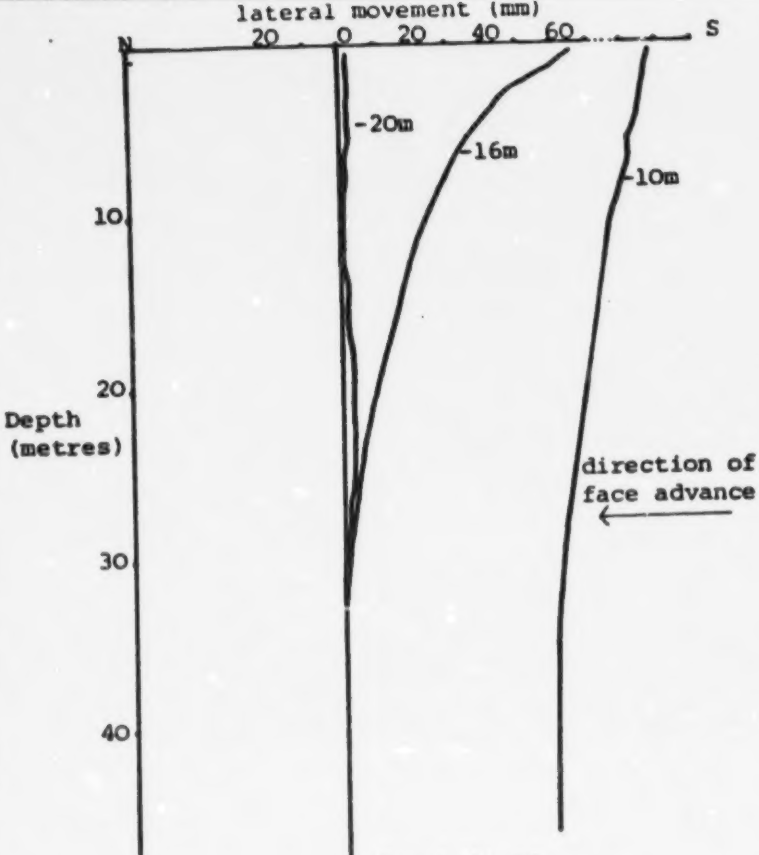
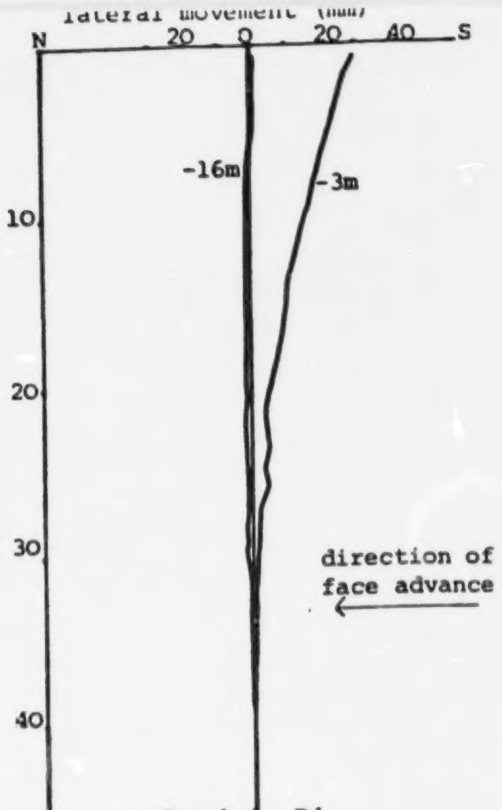


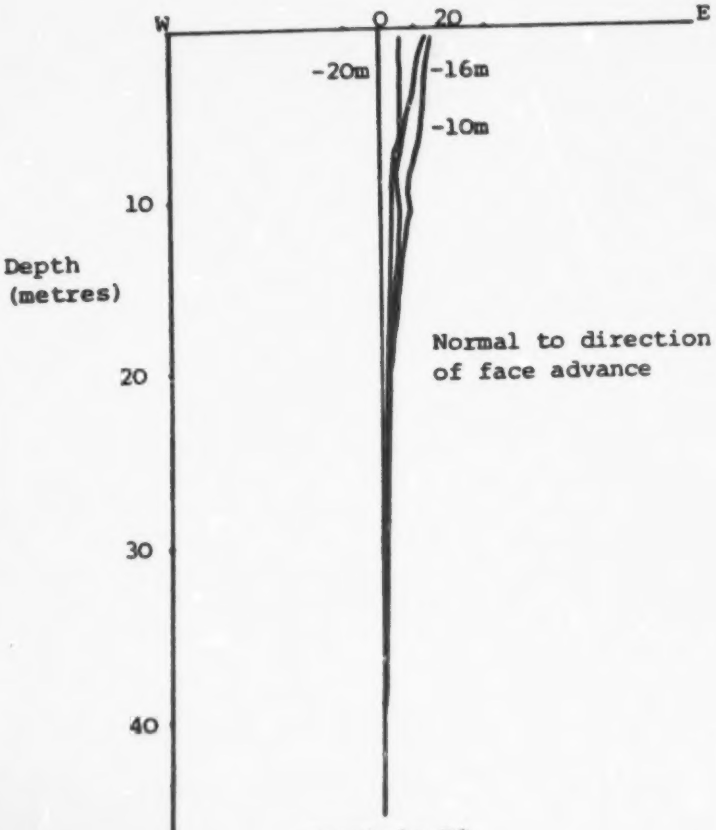
Figure 4a



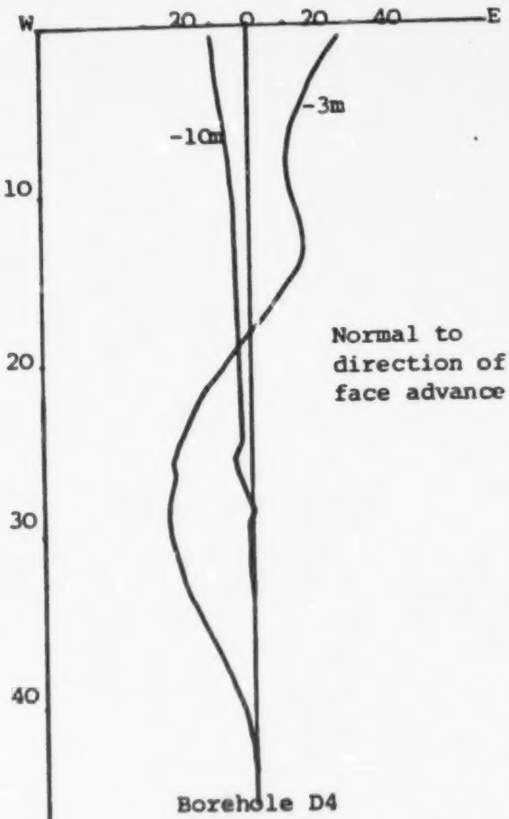
Borehole D3
Figure 5



Borehole D4
Figure 6



Borehole D3
Figure 7



Borehole D4
Figure 8

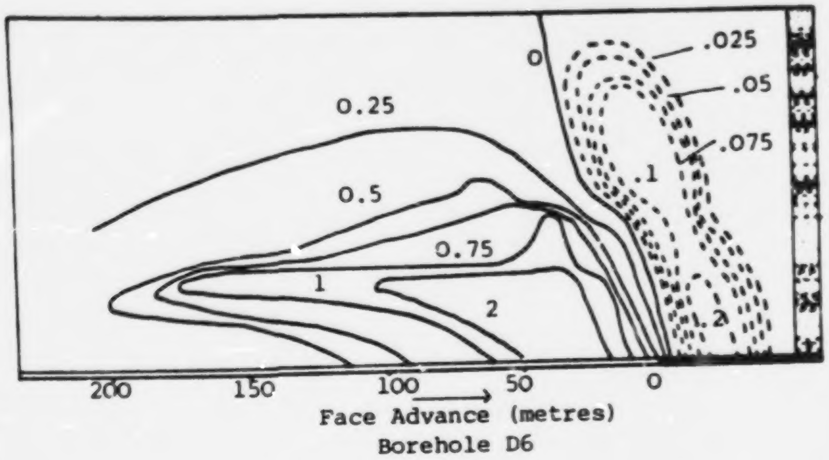
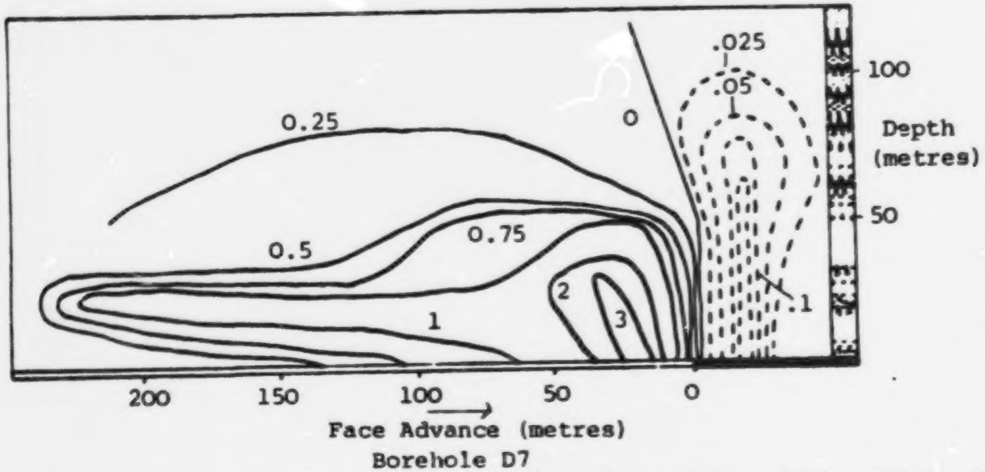


Figure 11



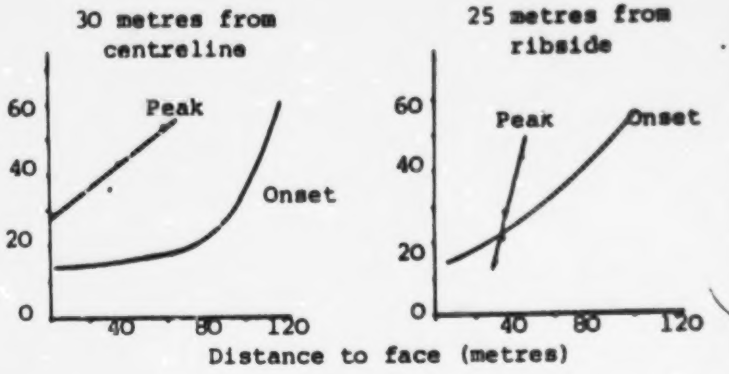


Figure 9

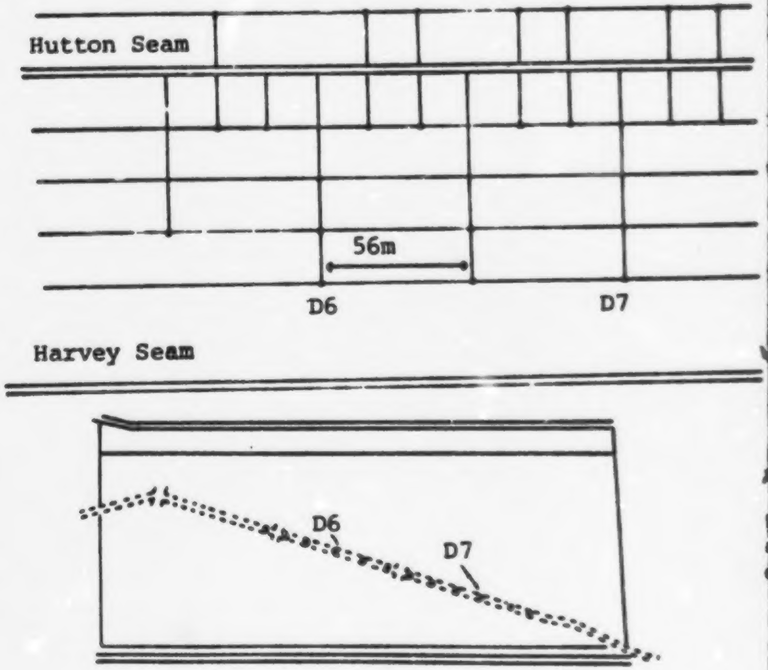

Hutton Seam
56m
D6
D7
Harvey Seam
D6
D7

Figure 10

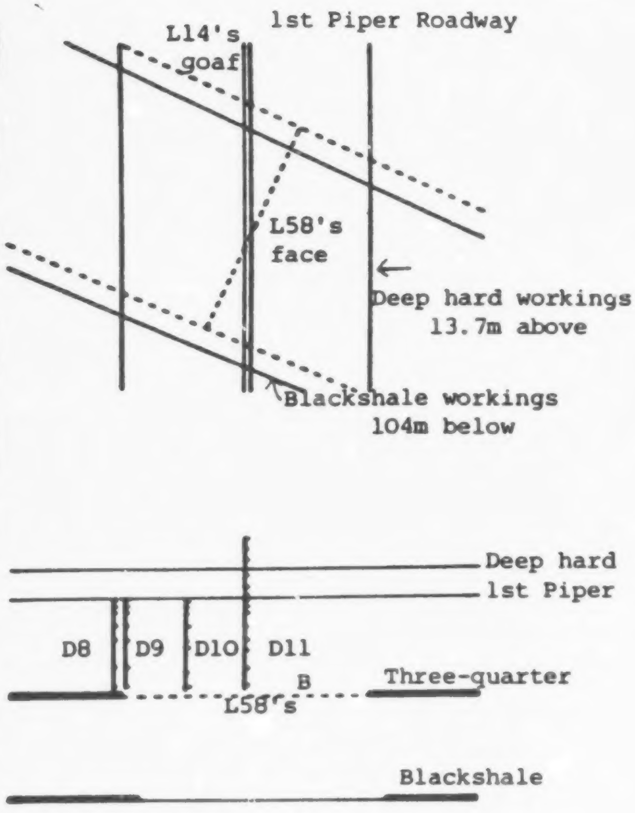
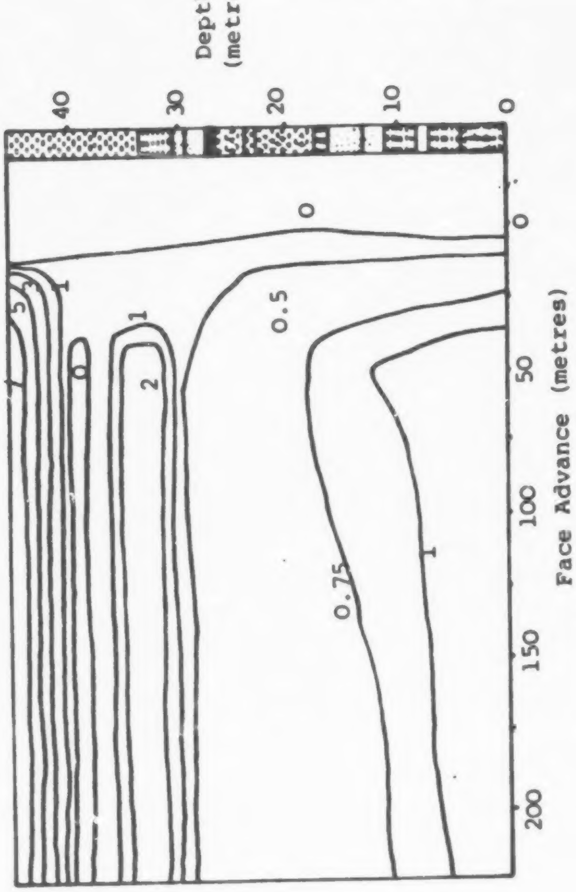
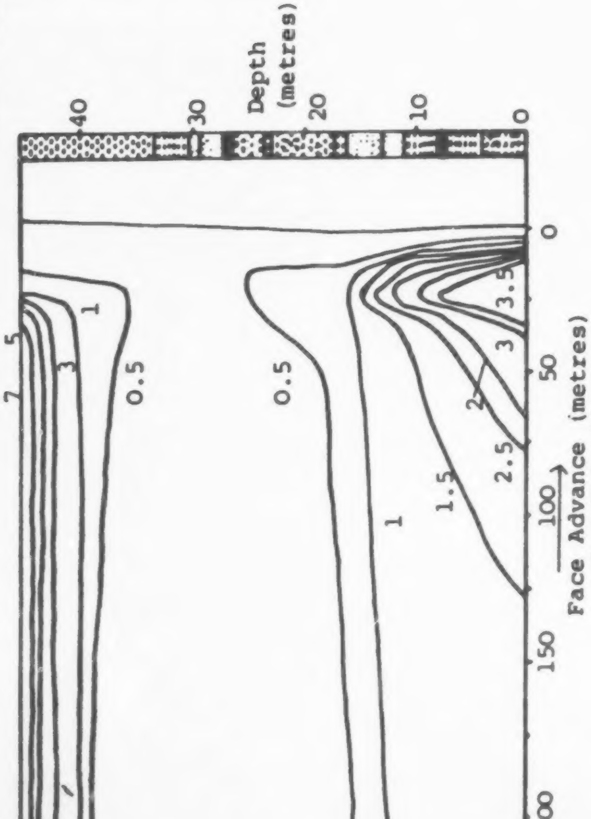

L14's goaf
1st Piper Roadway
L58's face
Deep hard workings 13.7m above
Blackshale workings 104m below
Deep hard
1st Piper
D8
D9
D10
D11
B
Three-quarter
L58's
Blackshale

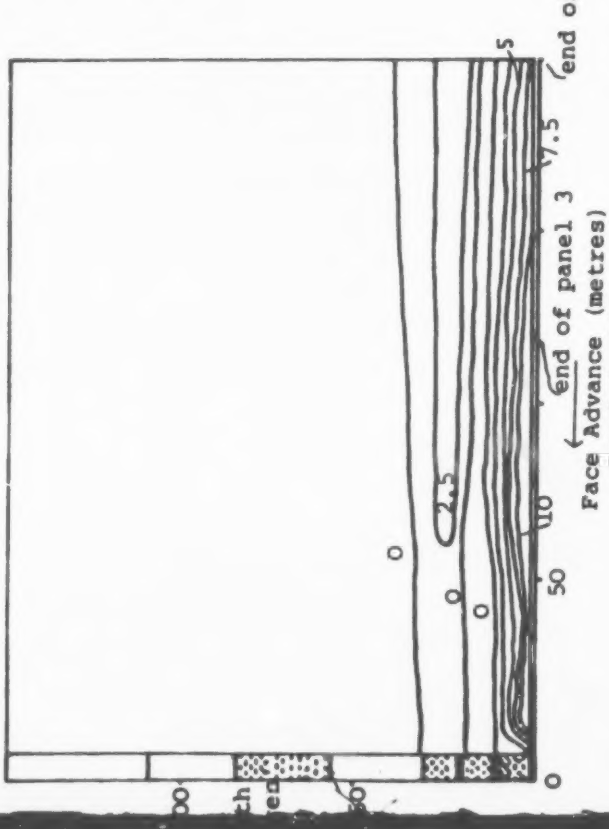
Figure 13



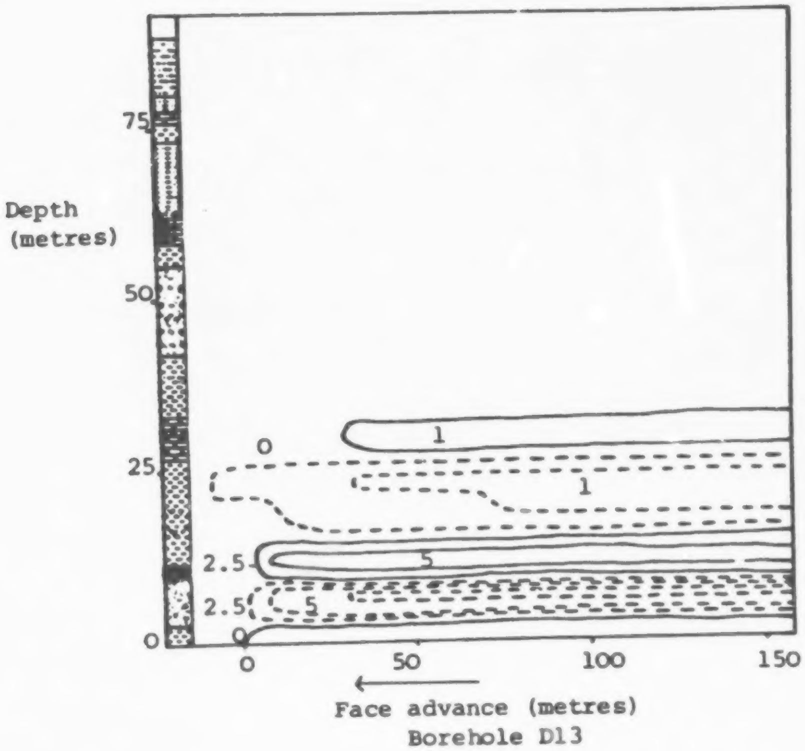
Borehole D10 Figure 14



Borehole D11
Figure 15

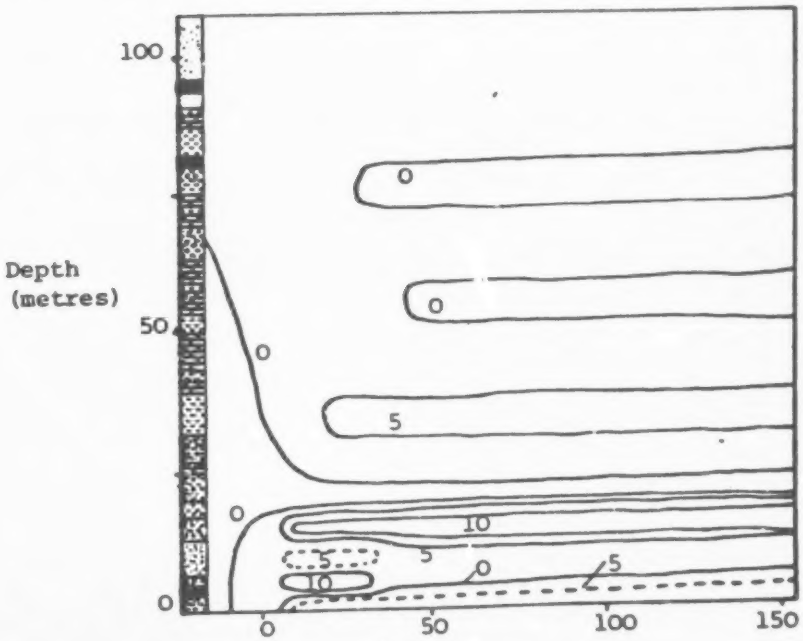


Borehole D12



Face advance (metres)
Borehole D13

Figure 17



Face Advance (metres)
Borehole D14

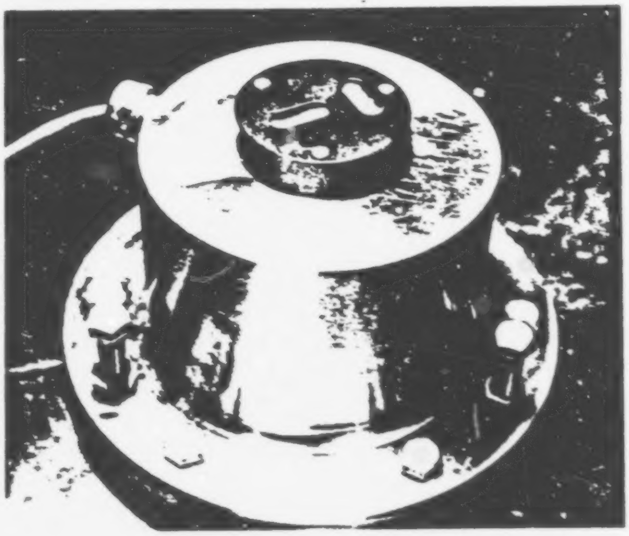
Figure 18

APPENDIX 5

5-1 Equipment Specifications

1. Terrascience Systems Ltd. Tiltmeter Specifications
2. Sinco Tiltmeter Specifications
3. Sinco Strain Meters
4. Geonor P-265 Vibrating Wire Extensometer
5. Automatic Settlement Plotter
6. Pneumatic Settlement Cell
7. Settlement Systems
8. Petur Settlement Systems
9. Sinco Horizontal Digitilt Inclinometer Sensor

TILTMETER



- **Available in uniaxial or biaxial configuration**
- **Rugged waterproof enclosure**
- **Robust fluid damped servo accelerometers for optimum performance**
- **Unaffected by temperature extremes**
- **Excellent long term stability**
- **Remote calibration capability**

GENERAL DESCRIPTION

Terrascience Systems Limited has been designing and manufacturing tiltmeter assemblies for use in geotechnical and structural projects for over ten years. The company developed the concept of the portable tiltmeter and pioneered the use of ceramic tiltplates for use with the portable unit. The current series of instruments, which are in widespread use for monitoring the stability and attitude of offshore drilling structures are the culmination of many years of experience.

The tiltmeters are available as either uniaxial or biaxial units, and they incorporate fluid-damped, closed-loop servo-accelerometers which are available in a selection of ranges, sensitivities and frequency responses. In all cases the accelerometers are characterized by having excellent long term stability, extremely low thermal drift, a high level output signal, and built in self calibration capabilities.

The unit shown is an example of a group of biaxial tiltmeters which were designed and built for use in an Arctic drilling structure where they would be intermittently submerged in salt water and subjected to temperatures as low as -50 degrees C. This unit has a range of +/- 6 degrees in both X and Y directions and a resolution of better than 2 seconds of arc (i.e. better than 1 in 20,000). The protective case is fitted with an accurate levelling bubble to facilitate initial installation by divers or construction personnel. This tiltmeter is fitted with an integral arctic submarine cable which passes through a waterproof penetrator. Alternatively it can be equipped with a waterproof multi-pin connector.

The accuracy, stability and frequency response of these tiltmeters is such that they also function extremely well as structural accelerometers. Assembled as biaxial or triaxial packages they have been used to monitor stuctural responses to both ice and wave impacts on ships and fixed structures.

TILTMETER SPECIFICATIONS

MECHANICAL

ENCLOSURE AND ASSEMBLY HARDWARE:	316 stainless steel
MOUNTING BRACKETS:	Can be bolted directly to concrete or bolted/welded to steel structures. Brackets available in either low carbon steel (A36) or high notch toughness arctic grade steel (G350A)
DIMENSIONS:	Diameter 10.0 ins. (25.4 cms.) Height 6.0 in. (15.24 cms.) Weight with mounting bracket 55 lbs. (25 kgs.) Bracket alone 22 lbs. (10 kgs.)

ELECTRICAL

RANGES:	Uniaxial, biaxial +/— 6 degrees (0.1G), +/— 15 degrees (O.25G), +/— 30 degrees (0.5G)
LINEARITY:	Better than +/— 0.05% full scale
HYSTERESIS:	Better than +/— 0.01% full scale
RESOLUTION:	Better than +/— 0.0005% full scale
INPUT VOLTAGE:	+/— 9 VDC to +/— 18 VDC
OUTPUT VOLTAGE:	+/— 5 VDC (std.)
FREQUENCY RESPONSE:	DC to 50 Hz (+/— 2 dB) standard 10 to 150 Hz (+/— 2 dB) optional
OPERATING TEMPERATURE:	—50 degrees C. to +80 degrees C.
SCALE FACTOR TEMPERATURE COEFFICIENT:	< 200ppm / degree C. (standard) < 100ppm / degree C. (optional)
STABILITY:	< 100 uG / degree C. (standard) < 50 uG / degree C. (optional)

TERRASCIENCE
SYSTEMS
LTD.

1574 West Second Avenue
Vancouver, British Columbia
Canada V6J 1H2
Telephone (604) 734-3443
Telex 04-54224

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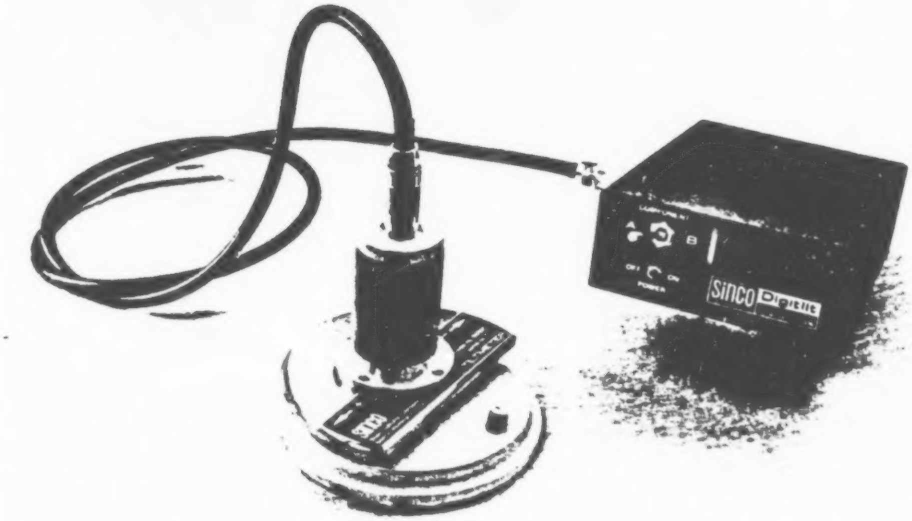
of Instrumentation Equipment

Printed in Canada



Model 50306 Digitilt® Indicator with Tiltmeter Sensor (model 50322) Placed on Ceramic Tilt Plate

General Description

SINCO Digitilt® Tiltmeters are rapid-reading, precise, and portable systems designed to periodically monitor horizontal and vertical tilt of structures, soil and rock masses. These Tiltmeter Systems combine rugged, lightweight, compact, and simple operation with low cost and high accuracy.

This accuracy can be applied to measurements of: 1) tilt of rock outcrops, benches of open pit mines, highway and railway cuts; 2) surface tilt of bridge piers, retaining walls; 3) profiling of surface settlements; 4) tilt of vertical walls and structures; and 5) subsidence in landslide areas, around earth or rockfill dams, and adjacent to building excavations.

In general, the Digitilt® Tiltmeters may be used where the failure mode of a mass may be expected to contain a rotational component. Temperature-stable ceramic Tilt Plates are bonded to the surface of the mass and experience the same angular rotation. The portable Tiltmeter Sensor is placed on each ceramic plate for monitoring. Periodic measurements of the tilt plates, enable the operator to compute the rate of angular deformation.

Basic Systems

There are two basic sensors for the SINCO Digitilt® Tiltmeter. The Model 50322 measures tilt in a horizontal plane and the Model 50344 measures tilt in a Horizontal and/or Vertical plane. The system includes Ceramic Tilt Plates, a Tiltmeter Sensor, and Digitilt Indicator.

Ceramic Tilt Plate

The ceramic plates are cast from specially formulated porcelain, with four sensor orientation pegs in the upper surface. Using grout or epoxy resin, the plates are bonded to rock, concrete, or metal. They are inexpensive, durable, non-corrosive, and have high dimensional stability.

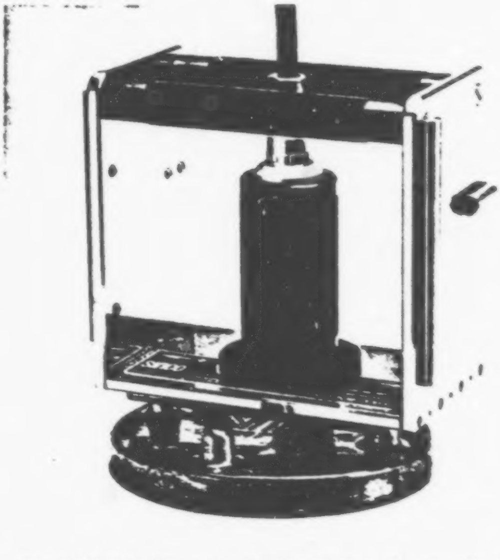
Tiltmeter Sensor

The portable tiltmeter sensor utilizes a closed-loop, force-balanced servo-accelerometer specifically designed for tilt measurements. It senses changes in tilt of the Tilt Plates. To operate, the sensor is oriented on three pegs of the Tilt Plate and an angle is read on the four-digit indicator display.

Digitilt Indicator

The standard Digitilt Indicators read 2 x sine Θ over the standard operating range of ±30° from vertical on a 4 digit bi-polar digital panel meter. This allows the user to measure change in angles to ±10 seconds of arc at vertical.

The Digitilt® Indicator is powered by an internal rechargeable battery and can operate continuously for at least eight hours under normal conditions. The Tiltmeter and Indicator, because of their light weight, can be carried and operated by a one man survey team, thus reducing data costs.



Model 50344 Tiltmeter Sensor in Reading Position on Ceramic Tilt Plate

All measurements should be taken, recorded, and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of such personnel.

SPECIFICATIONS

SYSTEM

Range: ±30° from the vertical, greater or smaller ranges of inclination available on special order
Sensitivity: 1 part in 10,000 (10 seconds of arc are equivalent of 200 microinches elevation difference on the pegs)
Temp. Coef: ±.003% of Range ±.003% of reading/°F

SENSOR, MODEL 50322

Sensing Element: A closed-loop, force-balanced servo-accelerometer, mounted with sensitive axis perpendicular to the surface of the plate.
Dimensions: 6-in. (15.2 cm) diameter, semi-circular base, 3 in. (7.6 cm) high
Material: Base: Steel, chrome plated
Accelerometer Housing: Aluminum
Carrying Case (for Sensor):
Aluminum-5 in. (12.7 cm) x 7 in. (17.8 cm) x 5 in. (12.7 cm)

SENSOR, MODEL 50344

Sensing Element: Same as Model 50322
Dimensions: 6.5 in. (16.5 cm) x 3.5 in. (8.9 cm) x 5.75 in. (14.6 cm)
Material: Base: Steel, chrome plated.
Accelerometer Housing: Aluminum
Carrying Case (for Sensor):
Aluminum - 7 in. (17.8 cm) x 10 in. (25.4 cm) x 7 in. (17.8 cm)

CERAMIC TILT PLATE, MODEL 50323

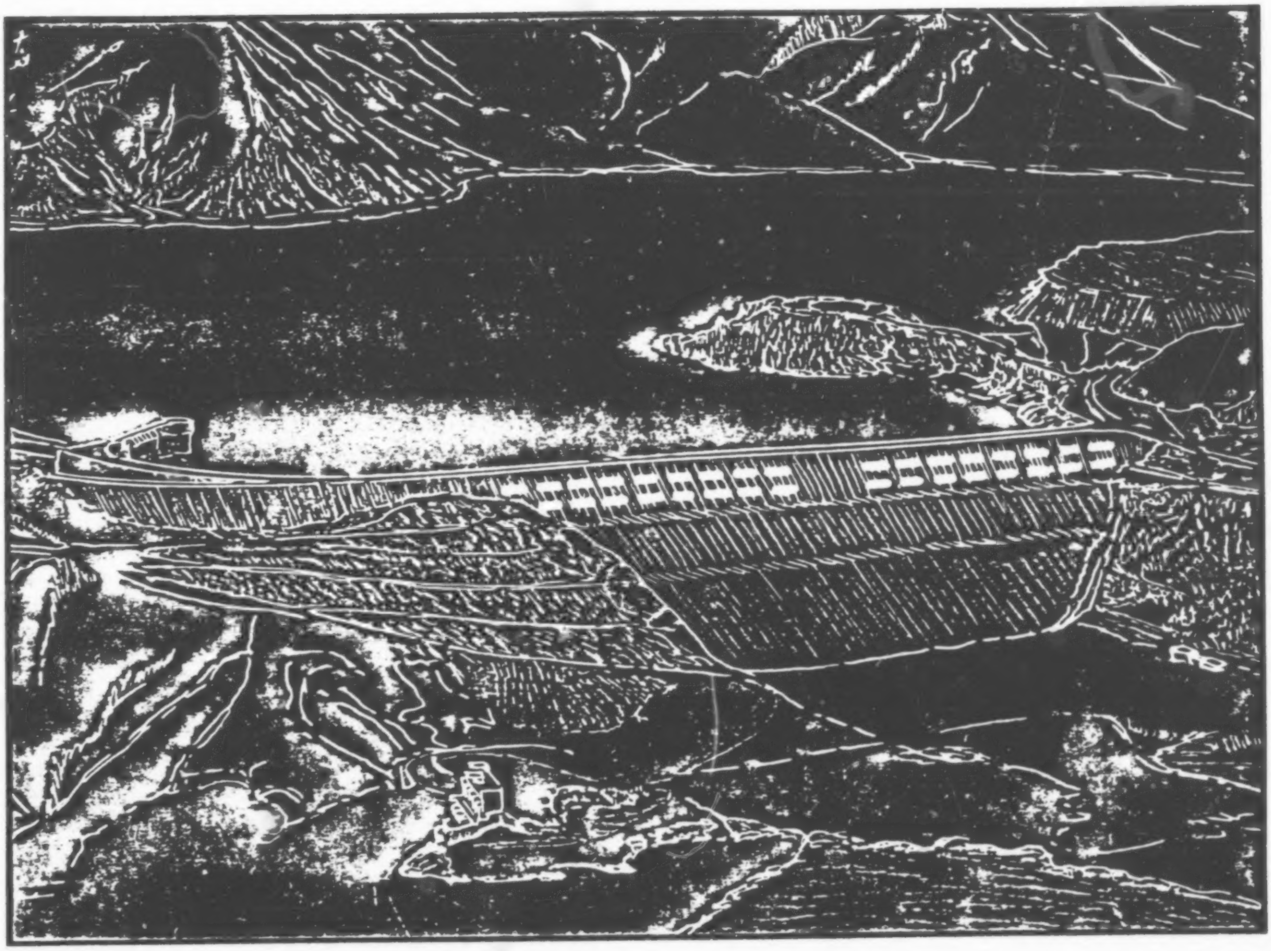
Dimensions: 6-in. (15.2 cm) diameter x 3/4 in. (1.9 cm) thick; 4 pegs equally spaced 4 in. (10.2 cm) apart

Material: Specially formulated porcelain

INDICATOR, MODEL 50306

Power: Self-contained rechargeable 6V battery
Operating Time: Approximately 8 hours fully charged
Dimensions: 5.62 in. (14.3 cm) x 2.37 in. (6 cm) x 9 in. (22.9 cm)
Weight: 5 pounds (2.3 kg)
Material: Aluminum Case

STRAIN METERS



SINCO

slope indicator company

Model 51701

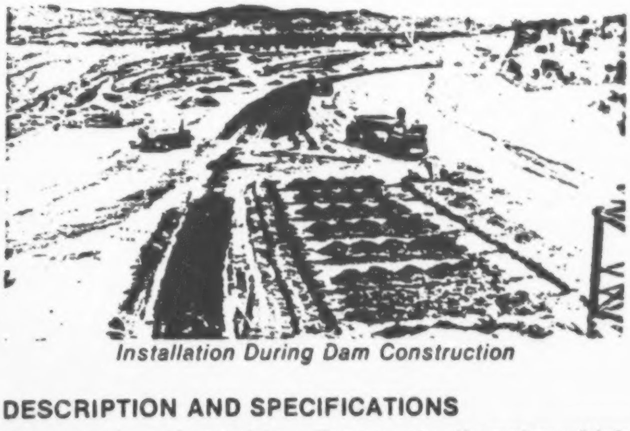
STRAIN METER

for earth structure deformation

- Linear potentiometer conductive plastic sensing elements
- Waterproof, direct-burial units
- Preassembled gauge lengths
- Optional measurement range and gauge lengths
- Rugged construction
- Portable digital indicator or automatic monitoring

Deformation in earth structures over an indefinite horizontal distance can be measured using the Model 51701 Strain Meter. These instruments are precision electrical displacement sensors which can be read remotely at a central point by means of portable indicators or by automatic data logging monitors. The Strain Meters have optional gauge lengths covering several feet. The sensors measure the change in gauge length linearly over a distance of several inches with a sensitivity of 10^{-3} times the range.

The Strain Meters are waterproof and designed for long-term operation buried within earth embankments such as dams, highways and reinforced earth structures. A typical installation in an earth dam is shown in the pictorial diagram. The Strain Meters are installed end-to-end, in line, and attached to each other in a continuous string to cover the total distance in the structure to be monitored.

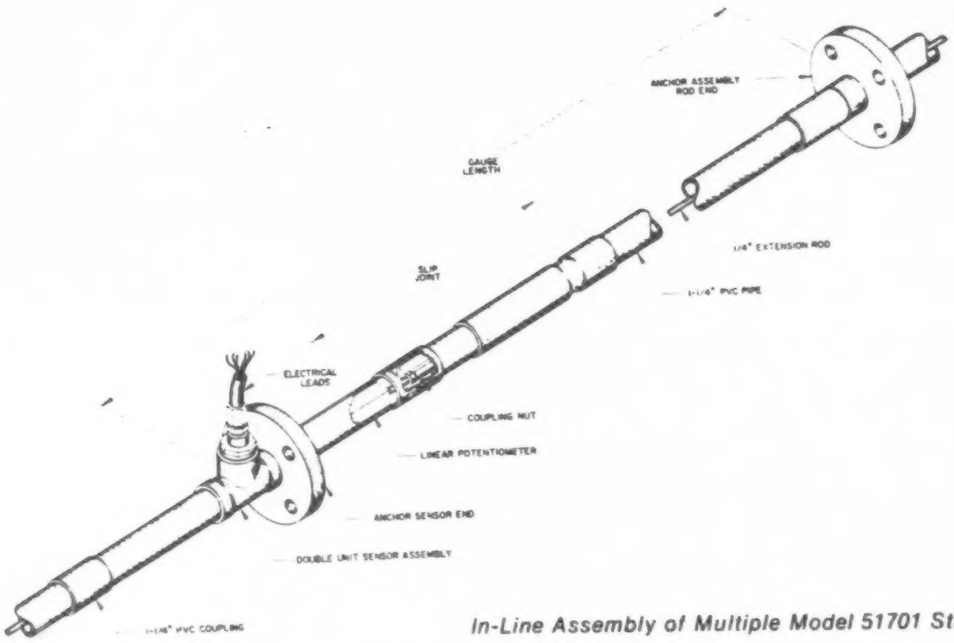


Installation During Dam Construction

DESCRIPTION AND SPECIFICATIONS

The sensing element is a linear potentiometer which has a resistance element of conductive plastic. The potentiometer and its electrical connections are potted and sealed within a protective enclosure of PVC pipe. A rod 1/4 inch in diameter connects the potentiometer shaft to the anchor point. The rod material is normally stainless steel. To eliminate temperature effects on long lengths, Invar rod is used. The rod is enclosed within PVC pipe. As shown for the 51701, two potentiometers are installed at the same anchor point. One 5-conductor cable for the two units is brought out the side of the double unit assembly through a PVC pipe tee. The standard cable is enclosed within 1/2 inch polyethylene tubing from Strain Meter to terminal

Placing Strain Meters In Trench


ANCHOR ASSEMBLY ROD END
GAUGE LENGTH
1/4" EXTENSION ROD
SLIP JOINT
1-1/4" PVC PIPE
ELECTRICAL LEADS
COUPLING NUT
LINEAR POTENTIOMETER
ANCHOR SENSOR END
DOUBLE UNIT SENSOR ASSEMBLY
1-1/4" PVC COUPLING

In-Line Assembly of Multiple Model 51701 Strain Meters

station. As an option, the cable may be enclosed in ½-inch flexible steel conduit with waterproof PVC jacket.

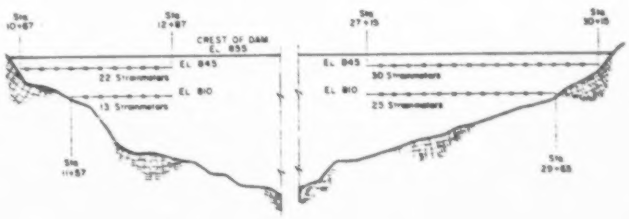
The displacement range of the sensors is optional and can be selected to meet requirements for measurements in rock or soil. The basic sensing unit is adaptable to other uses such as monitoring slope stability and structural joint movement.

The gauge length of the Strain Meters is optional; however, standard lengths are in 5-foot multiples.

APPLICATION AND INSTALLATION

The Strain Meters are particularly useful for monitoring strains in large earth structures. A number of large earth dams have developed cracks across the core soon after construction and during first filling of the reservoir. This cracking generally occurs near the abutments as a result of differential settlement and is frequently associated with irregularities in the underlying abutment rock. Sharp changes in slope resulting from abutment excavation may also contribute to tension cracking of the core. The 51701 Strain Meter, installed at critical locations, makes possible early detection and facilitates remedial work contributing to the safety and integrity of the structure. The Strain Meters are placed in a continuous straight line, end to end, with one end of the string anchored in the abutment. Such strings with multiple Strain Meters form an instrumentation system which is able to locate cracks within any of the gauge lengths.

To install the strain meters, a trench is excavated in the embankment surface three to four feet deep, 14 inches wide, with a level bottom. Lateral cutouts are made at the anchor points if extensions are used. Lateral trenches are made for the electrical cable. To minimize time at the site, the Strain Meters are pre-assembled to 50-foot lengths on a flatbed trailer. These are transported to the site and placed on boards spanning the trench at 10-foot intervals. Final adjustments of the initial setting are made as the entire string is connected together. It is then lowered to the bottom of the trench gradually by means of rope slings at each board. A 3- to 6-inch layer of screened core material is placed beneath and above the instrument if installed in the impervious core of a dam. Otherwise, fine sand should be used. Backfilling is completed using excavated material and should be carefully done using hand tools.


Sta 10+67
Sta 12+87
CREST OF DAM
EL 855
EL 845
22 Strainmeters
EL 810
13 Strainmeters
Sta 11+57
Sta 27+15
Sta 30+15
EL 845
30 Strainmeters
EL 810
25 Strainmeters
Sta 29+65

Typical Location of Strain Meters in a Large Dam

The electrical leads are normally brought to a common terminal and require trenching laterally or parallel for protection. Also, where they are run through pervious embankment materials, there should be one foot of sand beneath and above the leads. The leads should be run through rigid steel conduit when passing under roadways or where exposed on the surface at the entry to the terminal box. A suitable house enclosing the terminal boxes should be provided for protection.

Some of the large earth structures in which the strain meter is being used to monitor potential deformation includes the following:

- New Don Pedro Dam, California
- Mica Dam, British Columbia
- Ludington Pumped Storage Reservoir, Michigan
- Tarbela Dam, Pakistan
- Keban Dam, Turkey
- Bayano Dam, Panama
- Reinforced Earth Highway Embankment, California
- La Grande Hydro Project, Quebec
- Gathright Dam, Virginia

MONITORING INSTRUMENTS

Readings of strain meter outputs may be made manually by means of portable battery operated indicators, Models 51811 or 51762. These units are connected to remote terminal stations by means of a multi-conductor jumper cable. Automatic data logging equipment may be interfaced to have the capability of digital printout of all data, threshold comparison, alarm triggering, and also transmission of data via telephone line to office printout equipment.

SPECIFICATIONS

Sensor Resolution and Hysteresis: 0.1% Full Scale range

Sensor Linearity: 1.0% Full Scale range

Sensor Resistance: 10 K ohms

Sensor Output: Resistance ratio

Measurement Range: 6 in. standard (152 mm). Other ranges optional.

Gauge Length—Standard gauge length assemblies

51719	5 feet (152 cm)
51713	10 feet (305 cm)
51760	15 feet (457 cm)
51761	20 feet (610 cm)
51759	25 feet (762 cm)

Effect of Cable Length: .04% Full Scale/1000 feet

Temperature Effect on Sensors: None

Temperature Effect on Cable: 0.0001% Full Scale /°F/1000 feet

Housing Material: 1-1/4" schedule 40 PVC pipe

Outside Diameter: 1.66 in. (42 mm)

Reaction Flange at Anchor Point: Standard anchor is 1-1/4 in. schedule 40 PVC pipe floor flange, 4-5/8 in. dia. (117 mm).

Anchor Extensions: May be bolted to reaction flange to increase embedment coupling with compacted soil.

Aluminum angle P/N 51737, 1-1/2 in. x 1-1/4 in. x 1/8 in. x 24 in. (38 mm x 32 mm x 3 mm x 610 mm)

PVC plate P/N 51738, 10-1/2 in. x 8 in. x 5/8 in., (262 mm x 203 mm x 16 mm)

PVC plate P/N 51757, 11-7/8 in. dia. x 5/8 in., (301 mm x 16 mm)

Sensor Assemblies:

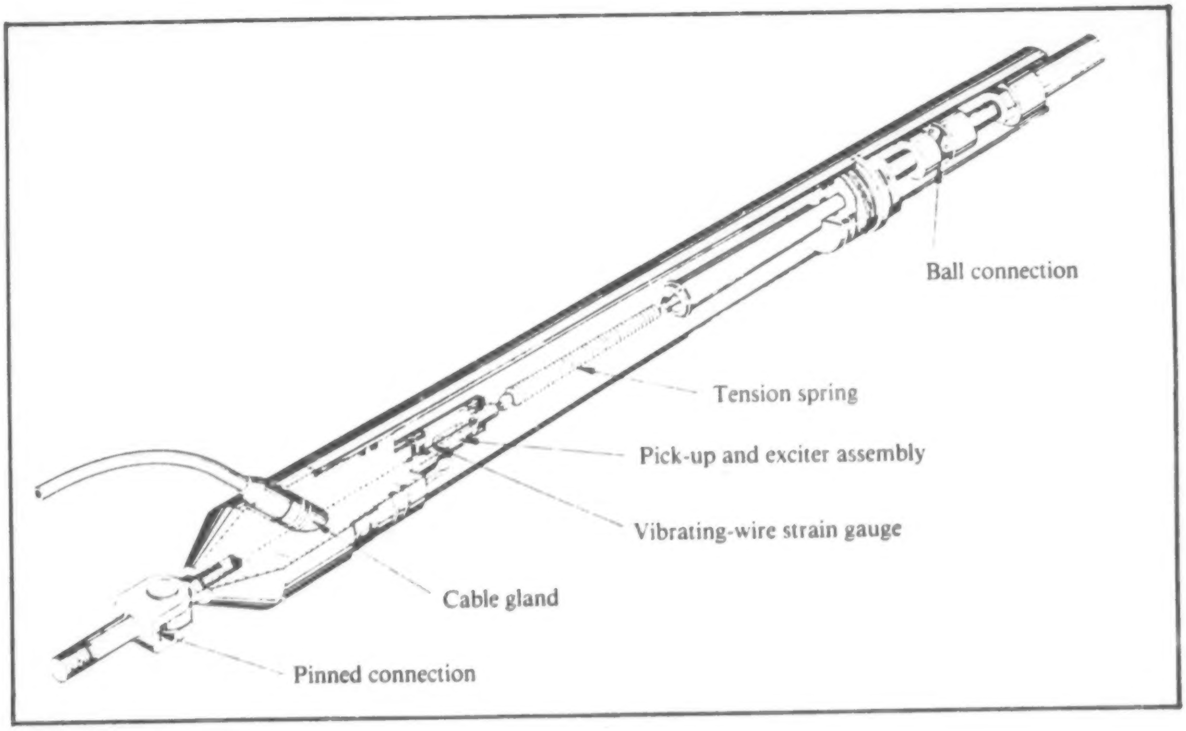
Single sensor assembly, Part No. 51749 used at the end of in-line string of Strain Meters.

Double sensor assembly, Part No. 51711 used at intermediate locations of in-line string of strain meters.

SINCO
Slope Indicator Company
3668 Albion Place North, Seattle, Washington 98103 U.S.A.
TWX: 910-444-2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073

Printed in USA (8-77)

GEONOR P-265 VIBRATING-WIRE EXTENSOMETER


Ball connection
Tension spring
Pick-up and exciter assembly
Vibrating-wire strain gauge
Cable gland
Pinned connection

P-265 Extensometer

- **Rugged construction**
- **Long term stability**
- **200 mm range**
- **Reinforced cable**
- **Reliable signal transmission (also with long cables)**
- **Pressure tight**

Introduction

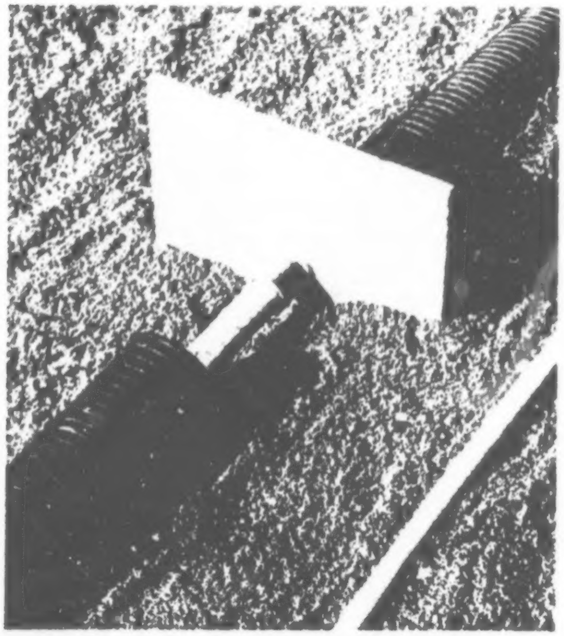
The P-265 electronic extensometer is specially designed to monitor displacements or strain in earth structures. The complete measuring system consists of three main parts:

- — extensometer
- — cable
- — read out instrument

The measuring system is based on a vibrating-wire gauge which can be read remotely via a cable coupled to a portable frequency indicator. Automatic data logger to suit customer's requirements can be supplied by Geonor (see specifications).

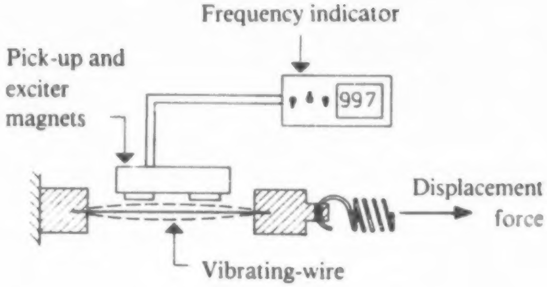
The extensometers are normally linked together with steel pipes and anchor plates to form a continuous chain over the distance to be monitored.

P-265 is designed to operate buried in an embankment and can withstand water pressures up to at least 20 bars.



Anchor-plate, protective tubing and signal cable.

Principle of operation



The basic principle of the vibrating-wire strain gauge is that the change in natural frequency of a stretched wire depends on the change of the tension in the wire. In this instrument one end of the wire is attached to the moveable head of the extensometer by a steel spring. A displacement of the extensometer is thus transformed to a variation in tension of the spring and also in the vibrating wire. Thus the frequency of the wire is a measure of the displacement between extensometer and anchor. The square difference of frequencies is proportional to the displacement.

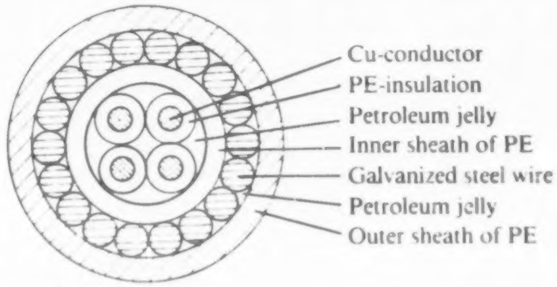
Application

The S-265 extensometer is particularly useful for monitoring internal deformation and cracking of dam embankment near the abutments. A number of dams have developed cracks across the core soon after the construction was completed or during the first filling and lowering of the reservoir. Most often the cracking occurs near the abutments due to differential settlements.

The extensometers are installed in a continuous chain over the length to be monitored. When installed at an abutment of a dam embankment, one end of the chain is anchored to the foundation rock. This type of installation provides a method to locate crack formation.

Cable

The P-430 cable is specially designed to withstand strong external forces in hostile environments. It is steel armoured and has a thick PE outside insulation. The space between the cable cores and also the space between steel armour wires is filled with petroleum jelly to prevent longitudinal leakages caused by light surface damage to the cable.



P-430 Signal cable

Read-out instruments

Reading of the P-265 electronic extensometer output may be performed manually or automatically. Manually the reading can be performed by a portable battery operated frequency indicator, P-520F, which is the general purpose read-out unit for all Geonor vibrating-wire gauges. It may be connected to the extensometer cable directly, or by means of a switchbox. Automatic read-out can be performed by a micrologger with the capability of digital print-out of all data.

Low cost 2—8 ch frequency logging units are also available. Transmission of data via a telephone line to a control center and alarm triggering of such equipment is available from Geonor.

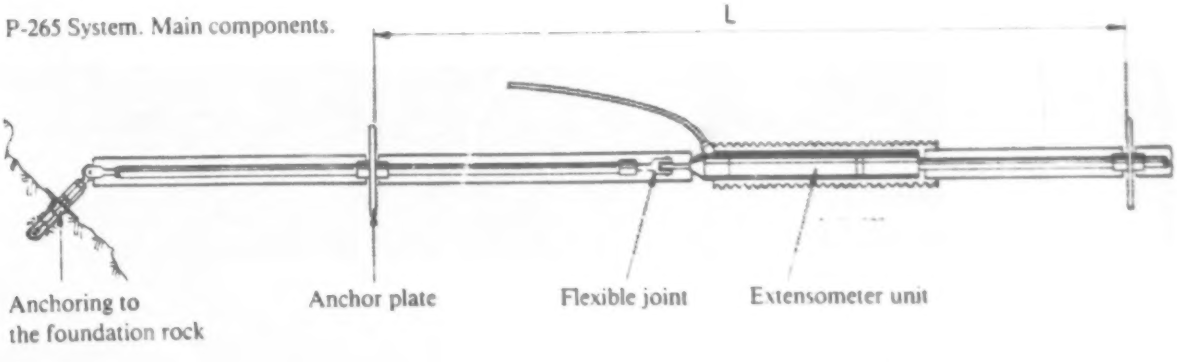
Installation

The P-265 extensometers are installed in the embankment on a level surface, either in an excavated trench, 1 m deep and 0,5—1 m wide or on a compacted bedding, 1—2 m wide. If installed in the impervious core of a dam, a 100 to 150 millimeter layer of screened core material should be placed beneath and above the instrument. Otherwise a sand material with 0 to 5 mm grain size is recommended. If installed in a coarse rockfill material a filter fabric should be placed between the sand and rockfill material to prevent large stones from penetrating into the fine material surrounding the instrument.

The cable should be buried in a cable trench parallel to the extensometer trench. Normally cables from an extensometer chain are connected to a multicable in a special embankment junction box. The multicable is then routed to the monitoring equipment.

The extensometers are usually installed horizontally and laid parallel with the crest to measure strains along the longitudinal axis of the dam. The extensometers are linked together in 4 to 12 m long sections by universal joints, extension pipes and anchor plates to form continuous extensometer chains of varying length depending on the geometry of the dam. Continuous extensometer chains up to 120 m in length have been installed using this procedure. If the extensometers are extended to the abutments the end of the chain of extensometers is anchored to bedrock by means of rockbolts.

P-265 System. Main components.



Specification

P-265 extensometer

Measuring range: 150 or 200 mm FR
Linearity: 1% FR or better
Hysteresis: 2% FR or better
Frequency range: 800 - 2000 Hz
Signal span: Max. 1000 Hz
Calibration: Individual with 1/100 mm resolution
Material: Cadmium plated steel

Dimensions	**Size**	**Weight**
P-265 Extensometer	OD57 × 760 mm	6 kg
P-265-30 Extension pipe	1'' BSP × 4,6 m (other lengths on request)	0,7 kg/m
P-265-36 Anchor plate	300 × 300 × 10 mm	7 kg

Accessories

P-430 cable	OD16 mm Max tensile strenght: 12 kN
P-265-29 Protection tubing	OD63 mm PE tubing
P-265-30 1'' BSP Extension steel pipe	Standard steel pipe with connector, 4,6 m long
P-265-26/27/28/33 Rock anchor system	Expansion bolt OD30 mm Washer OD150 mm Connector Ball connection
P-544 Watertight junction box	For embedding in soil 2—10 gauge-cables and one multicable
P-265-36 Anchor plate	Steel plate, 300 × 300 × 10 mm with 1'' BSP connectors

Read-out equipment

	P-520F	Micrologger	Frequency logger
Power	12 V NiCd 300 mAh 220 V (110 on request)	24 VDC, -6V, (+ 8V optional) 255 VAC, ±15V, 50-60 Hz	220 VAC 12 VDC
Battery capacity (before recharging)	20 h	—	—
Frequency range/display	0-9999 Hz	20 char. alphanumeric	0-9999 Hz (0-9999,9 Hz optional)
Accuracy	± 1 Hz	—	± 1 Hz (± 0,1 Hz optional)
Temp. range	-10°C — +70°C	0—50°C	0—40°C
Size (w × d × h) in mm	95 × 175 × 50	19'' rack	340 × 250 × 140
Digital printer	—	Olivetti 1800 series Dot matrice	Termoprinter
Separate leaflets available	Yes	Yes	Yes
No of channel	1	32 to 128 in blocks of 32	2, 4, 8

Separate leaflets are also available for cable, glands and junction boxes.

Automatic Settlement Plotter

(Double Fluid Settlement Gauge)

Applications

Automatic and semi-automatic profile measurement of vertical movements in soils along the axis and throughout the entire length of a flexible tubing installed in the foundation or structure under study.

Applications include –

- Settlement profile measurements in foundations and at intermediate construction levels of dam or road embankments, bridge approaches, structures founded on foreshores and reclaimed land.
- Settlement profile measurements of dam embankment and reservoir impervious membranes and linings.
- Settlement profile measurement below large storage tanks.
- Settlement profile measurement of buried pipelines.

Operating Principles

A continuous length of small bore plastic tubing up to 1200 metres long is placed in the foundation or structure during construction to form a continous horizontal loop, both ends being terminated at the readout point. Prior to measurement the tubing is filled with air free water. During the measuring phase a water/mercury interface is formed which is pumped along the length of the installed tubing at a fixed advance rate. By monitoring the hydraulic head difference produced at the level of the water/mercury interface, a continuous record of the interface elevation is obtained. On completion of the measuring sequence, the mercury is removed from the installed tubing and replaced by water. Two basic operating modes are available in the standard equipment –

Semi Automatic (incremental measurement). Relative elevation data is displayed at pre-selected distance increments (1, 2, 5 or 10 metres of tubing length) together with accumulated distance in metres from the start (datum) point. The data is manually recorded.

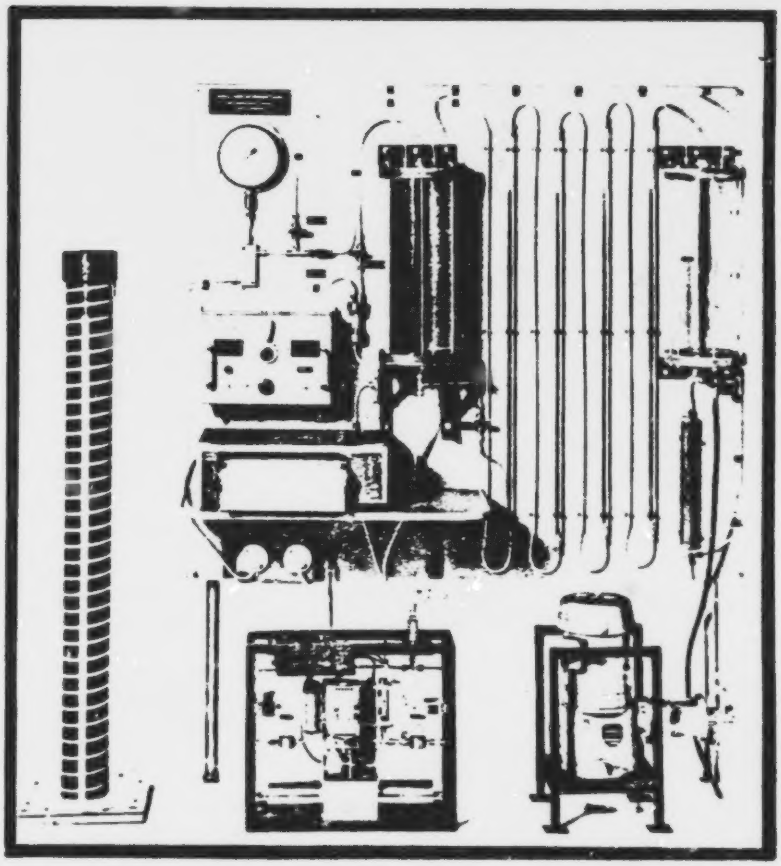
Automatic (continuous measurement). Data is recorded as a continuous elevation against distance on an electrical chart recorder.

Advantages and Limitations

- A unique measuring technique which provides continuous profile data to within ± 1cm of elevation over tubing lengths in excess of 1km.
- The portion of the system embedded in the structure is rugged, inexpensive and simple to install (small bore nylon tubing).
- The Automatic (unattended) mode of operation provides continuous profile data in graphical form scaled directly in engineering units thus eliminating manual data recording.
- The routing of embedded tubing may be planned to traverse potentially critical areas within the structure where, due to changes in underlying foundation conditions, or transitions, significant differential settlements are envisaged. Several routings may be terminated at one readout point.
- The standard equipment is designed to measure the level of tubing at a range of elevations lying between the centre of the operating panel and a level 3.5 metres below. This range must accommodate the expected settlement.
- In very cold climates precautions may be necessary to prevent freezing of water in the equipment.

Performance

Tubing lengths up to a maximum of 1200 metres. Elevation range normally 3.5 metres. This may be increased to 5 metres with modified equipment and reduction in resolution. Mercury feed rate – 2 metres of tubing per minute. Elevation display in metres and centimetres with respect to a datum elevation, normally the datum plate of the calibrated riser pipe assembly. Elevations above datum level are displayed with positive sign, those below with negative sign. Accuracy of elevation display ± 1 cm. Accumulated distance display in units of one metre from start of test cycle. Accuracy of distance display directly proportional to the stability of mains supply frequency (50Hz and 60Hz versions available). Pre selection of chart recorder scale and speed is available.



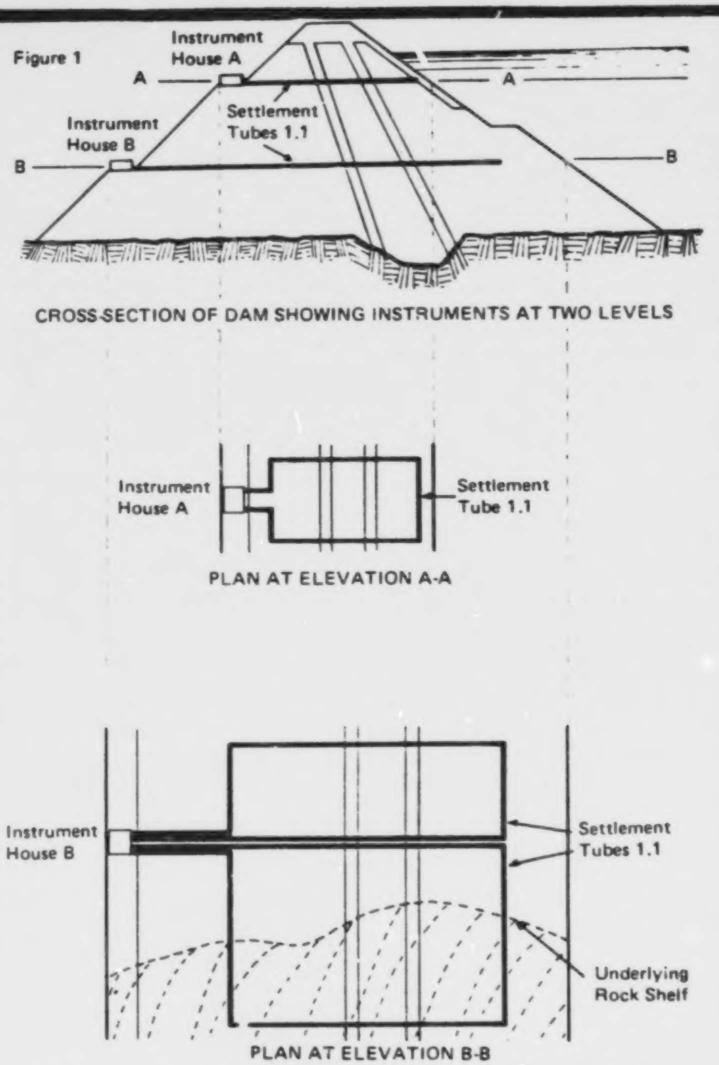
Instrument House Equipment for Automatic Settlement Plotter

Installation

INSTALLATION

Figure 1 illustrates the general features of a typical installation.

Figure 1



CROSS-SECTION OF DAM SHOWING INSTRUMENTS AT TWO LEVELS

PLAN AT ELEVATION A-A

PLAN AT ELEVATION B-B

Automatic Settlement Plotter (Double Fluid Settlement Gauge)

Instrument House

The Operating Panel (6S 2.1) is permanently wall mounted at a convenient working height and connected to the installed tubing by means of the Calibrated Riser and Datum Plate Assembly (6S 2.2) secured to the floor, or mounted on a small plinth. Since all data produced during each reading sequence is in the form of elevation relative to the Datum Plate Level, it is essential that provision be made for normal surveying of this plate. The installed tubes are connected at the terminals of the Datum Plate and routed horizontally via the instrument house entry duct (6S 2.3) into the embankment fill It is desirable, where layout permits to set the level of the Datum Plate to that of the embedded tubing loop.

Since mercury is used in this system, effective instrument house ventilation is necessary. A reliable mains power supply is essential for the operation of this system. All instrument house items with the exception of the Operating Panel (6S 2.1) and Calibrated Riser and Datum Plate Assembly (6S 2.2) are designed as portable units which may be moved from one instrument house to another as required.

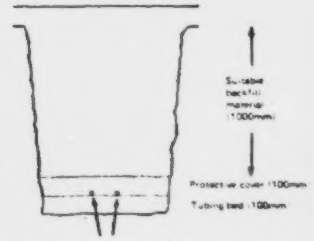
Installed Tubing

The settlement tubing (6S 1.1) is placed in a trench approximately 1m. deep to avoid damage from construction traffic. In an embankment, fill is placed over the entire area to be instrumented, until the level is at least one metre higher than the proposed installed tubing elevation. The trench is excavated to a sub-grade level approximately 100mm lower than that of the nominal tubing level. All loose material is removed from the trench floor and survey pegs placed at 5 to 10 metre increments along the edge of the trench. A compacted layer of suitable sieved material (2mm maximum particle size) 100mm. thick is prepared as a protective bed for the tubing. With reasonable care a practical level tolerance of ± 50mm is possible, though this is not critical. The tube is laid in the trench and snaked to allow for lateral strain. Where the return tube is in the same trench, a minimum separation of 50mm. is recommended. At no point should the tubing be set less than 100mm. from the trench wall. Snaking may involve up to 5% addition to linear tubing length. A 100mm. layer of sieved material is placed over the tubing and thoroughly compacted. Backfilling of the trench is completed in compacted layers of selected material. (See Figure 2.)

Since the Automatic Settlement Plotter provides data relative to the actual tubing length, the constancy of the relationship between tubing length and actual linear progression along the trench relies entirely on the consistency of the degree of 'snaking'.

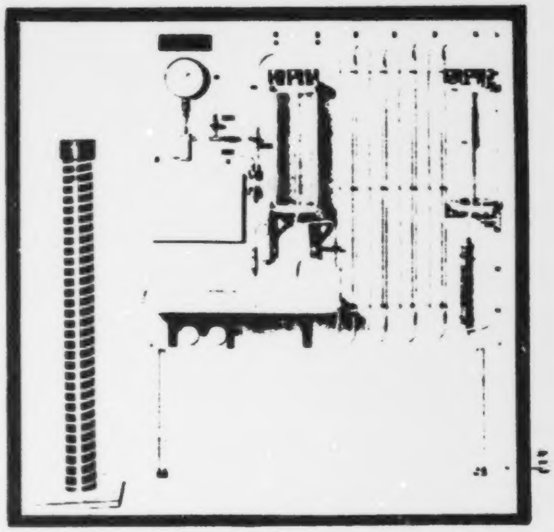
It is therefore recommended that reference ramps are included in the tubing loop at a few intermediate locations, especially in long loops. These will be readily identifiable in the readout data. Though dimensions of the ramps are not critical, a rise of 100mm over one metre, a horizontal portion of three metres, and a return to original level over one metre has been found adequate for this purpose.

Figure 2



TYPICAL TRENCH DETAIL

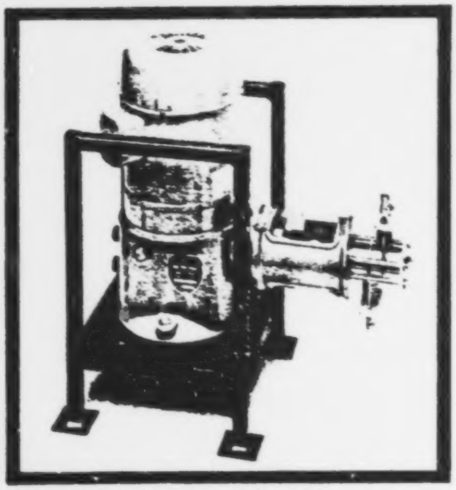
PERMANENT EQUIPMENT ▶



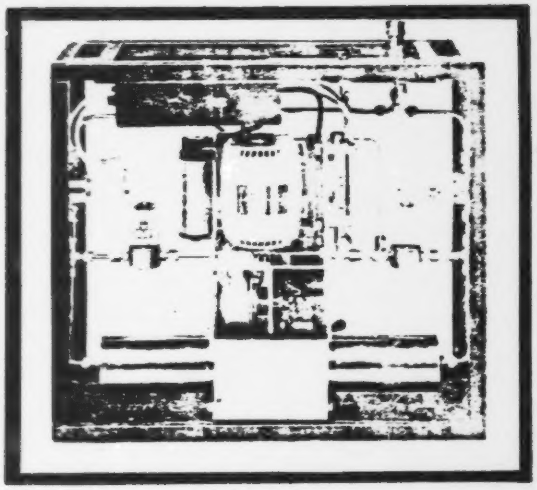
Terminal panel 2.1, calibration riser pipe and datum plate assembly 2.2.

PORTABLE ITEMS

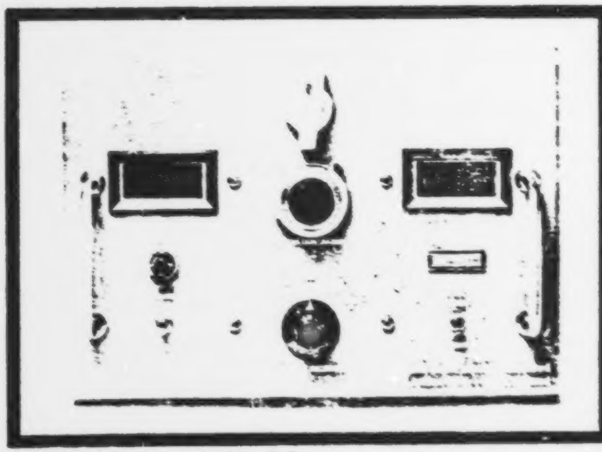
▼



Water circulating pump 2.6 or 2.7.



Mercury drive pump 2.4 or 2.5.



Digital display unit 2.8 or 2.9.

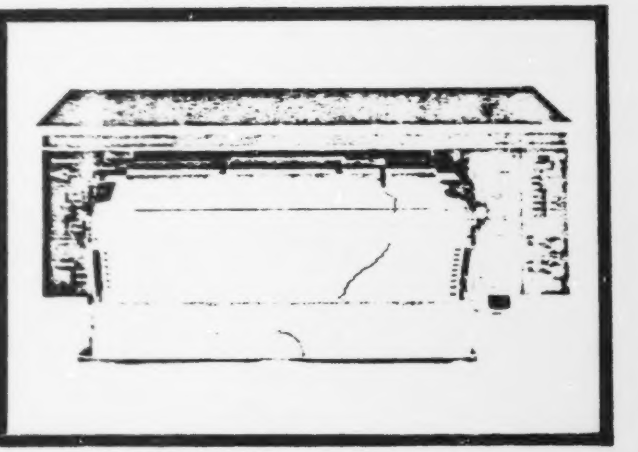


Chart recorder 2.10 or 2.11.

Specification

To order equipment please quote the data sheet and specification numbers, the name of the item and the quantity required, for example 6S 2.1 Terminal panel 2 No.

1. Settlement Tubing and Fittings

1.1 Settlement Tube. Thick wall low friction nylon tube 6.4mm o.d. supplied in unbroken lengths on a drum containing 500m. Dimensions 610mm diameter x 360 mm. Weight 19kg. per 500m.
1.2 Tube Coupling. Stainless steel 6.4mm nominal diameter straight compression coupling. Weight 40 g
1.3 Redistilled Mercury. Supplied in sealed plastic bottles. Allow 9kg per 100m of installed tube plus 14kg for operating reserve. Weight one bottle 2.5kg.

2. Instrument House Equipment

Permanently Installed Items

2.1 Terminal Panel. Designed for wall fixing, the panel which is mounted on a detachable steel frame incorporates all necessary reservoirs, gauges, back pressure system, hydraulic valves, pipework, electrical transducer, wiring and outlets to enable connection to portable pump units, readout equipment and electric supply. Dimensions 1310mm high x 1460mm wide. Weight 62Kg.
2.2 Calibration Riser Pipe and Datum Plate Assembly. Free standing unit. 100mm nominal diameter P.V.C. pipe with graduated scale set vertically and helix wound with two nylon tubes, complete with base datum plate containing flat spiral tubes and connections for 1.1 settlement tube. Dimensions 1330mm height x 300mm x 300mm. Weight 8.5kg.
2.3 Entry Duct. Instrument house entry duct comprising 600mm long heavy gauge rigid P.V.C. flanged tube with cover plate, neoprene gasket and flange bolts. The cover plate incorporates up to 8 individual waterproof glands to take 1.1 settlement tube. Weight 3.4kg.

Portable Items

2.4 and 2.5 Mercury Drive Pump, incorporates two cylinders set back-to-back and driven by a common reciprocating piston. Mercury delivery rate 6cc per minute (2m tube length per minute). Including all control and alarm circuits, pump cylinders, pistons, hydraulic tubing, valves, quick connect couplings etc. all in stainless steel. 2.4 for 230 volt 50Hz. 2.5 for 115 volt 60Hz. The unit is housed in a carrying frame 480mm x 165mm x 420mm high. Weight 14kg.
2.6 and 2.7 Water Circulating Pump, single piston metering pump with micrometer delivery adjustment over the range zero to 13 litre per hour. The piston, cylinder and couplings are of stainless steel construction 2.6 for 230 volt 50Hz. 2.7 for 115 volt 60Hz. The unit is mounted in a carrying frame 255mm x 255mm x 410mm high. Weight 10kg.
2.8 and 2.9 Digital Display Unit, incorporating electronics, power supplies, ramp amplifier, signal conditioning, control and switching circuits.
Digital distance measurement with LCD indicating accumulative distance in metres. On "Continuous" operating mode, display changes at 1m increments. On "Incremental" operating mode display changes at 1, 2, 5 or 10m increments as dictated by mode switch setting.
Elevation Measurement with LCD indicating elevation in metres and centimetres. Reading positive above datum and negative below datum. On "Continuous" operating mode display changes with input variations. On "Incremental" operating mode display changes at 1, 2, 5 or 10m distance increments as dictated by mode switch setting. 2.8 for 230 volt 50Hz 2.9 for 115 volt 60 Hz. The unit is provided with quick connectors and housed in a steel case 320mm x 170mm x 220mm high supplied with shock resistant padded carrying case. Weight 7.2kg.
2.10 and 2.11 Chart Recorder. Single line chart recorder incorporating 250mm wide paper graduated in 100 divisions. Switched ranges enabling paper width to represent 1, 2 or 5 metres of elevation change. Switched chart speeds (10 ranges) covering range from 1 division = 10 cm installed tube to 1 division = 120 metres installed tube. 2.10 for 230 volt 50Hz. 2.11 for 115 volt 60Hz. Housed in a steel carrying case 440mm x 133mm x 350mm. Weight 9kg.

3. Accessories

3.1 Chart Recorder Paper, 20m long Z fold pack supplied in packs of 5. Weight 2.4kg.
3.2 Chart Recorder Pens. Supplied in packs of 10 Colour Red or Blue. Weight 400g.
3.3 Tool Kit, comprising steel tool box, spanners, screwdrivers, pliers, cutting knife, steel measuring tape, service kits for mercury and water pumps and chart recorder. Weight 4kg.
3.4 Coloured Adhesive Tapes. 9mm width. Set of 10 reels, 20m long in assorted colours. One set suitable for marking 5000m tube.
3.6 and 3.7 Power Stabiliser Pack, comprising mains supply battery charger, float battery and DC/AC transverter. (frequency regulation ± 0.25 Hz). 3.6 for 230 volt 50 Hz. 3.7 for 115 volt 60 Hz.

Pneumatic Settlement Cell

Applications

The measurement and control of vertical movements including:

- Construction control of road embankments and earth dams.
- Settlement and heave of oil tanks and building foundations.
- Monitoring of bridge piers, abutments and retaining walls.
- Control of subsidence.

Operating Principle

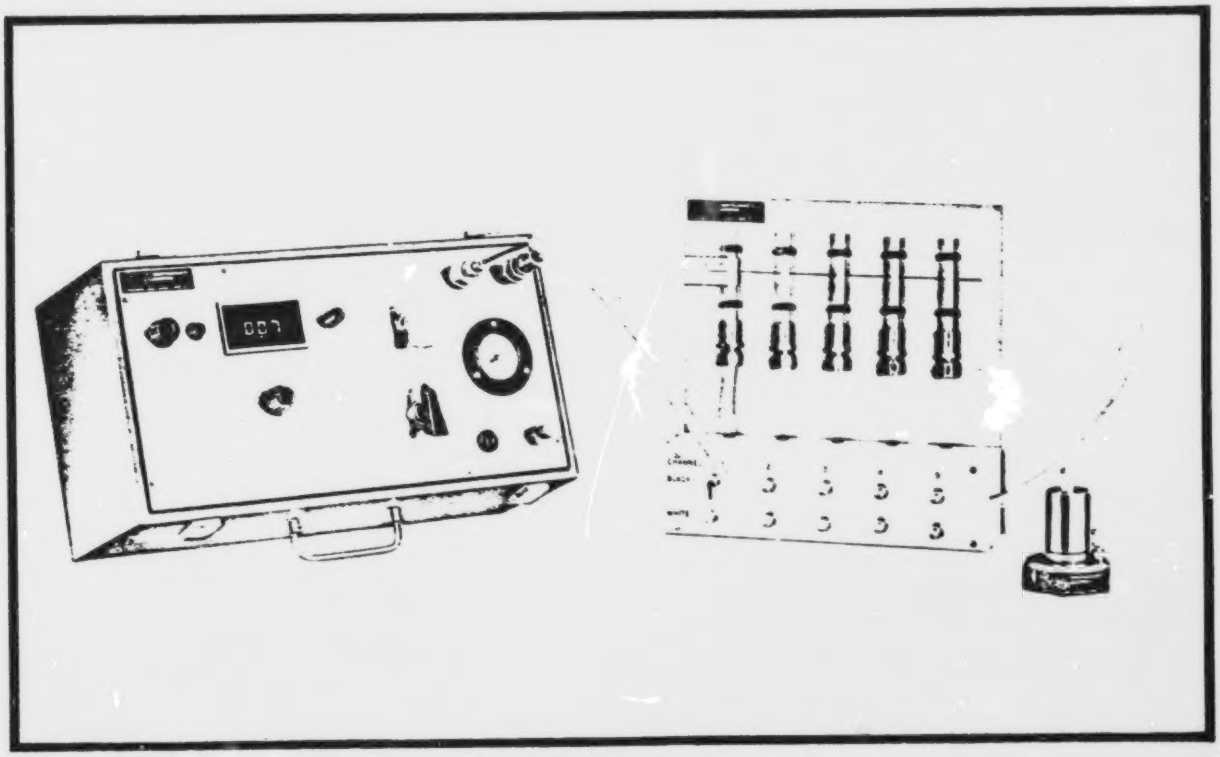
The cell consists of a pneumatic transducer with an integral mercury chamber. Triple nylon tubing extends from the cell to the readout located in stable ground. One of the tubes is filled with mercury and is connected at one end to a datum sight tube and at the other to the mercury chamber. Vertical movement of the cell relative to the readout location results in a change in mercury pressure within the chamber. To measure the pressure change, and hence the amount of settlement or heave, pneumatic pressure is supplied from the portable readout unit to one side of a flexible diaphragm valve incorporated in the cell transducer. When the supply pressure is sufficient to balance the mercury pressure on the reverse side of the diaphragm, the valve opens allowing flow along the return tube to a detector in the readout unit. The balance pressure is recorded on a Bourdon tube gauge or digital display. The mercury level in the datum sight tube may require small adjustments from time to time, to compensate for volume changes that occur due to stretching of the triple tubing and changes in temperature.

Advantages and Limitations

- Reliable, simple to install and to read.
- Measurements can be made beneath concrete and earth structures at locations which are inaccessible to other types of instrument.
- No vertical rods or tubes to interfere with construction.
- Unaffected by temperature variations and lateral movements.
- The identical portable readout units can be used in conjunction with pneumatic piezometers and pressure cells.
- Large range but limited precision (±1cm).
- The pneumatic cell gives movement at a single point; for a complete settlement profile see Data Sheets 5S and 6S.

Performance

Portable meter readout 5.1 has a range of 2m, giving an overall accuracy of ±1cm settlement or heave. Portable digital readout 5.2 has a range of 20m, giving an overall accuracy of ±1cm settlement or heave. Cells should be installed at a level lower than the datum tubes at the readout location; the difference in elevation between the cells and the tubes should be less than the range of the readout unit, making allowance for the anticipated settlement or heave. All components are waterproof, robust and proof against corrosion.



PNEUMATIC EQUIPMENT FOR MEASURING SETTLEMENT; from right to left the cell, connected through the terminal and datum panel to the portable digital pneumatic readout.

Installation

Installation in Soil and in Fill

A terminal location is selected, preferably in stable ground away from the anticipated zone of settlement. Terminal panel 3.1 or 3.2 is secured to the wall of an instrument house or in a manhole well. A trench 0.5 to 1 metre deep is excavated to accommodate the tubes and the cells. The cell locations are carefully marked out, and pockets 30 x 30 x 30cm in size are dug in the base of the trench to receive each cell.

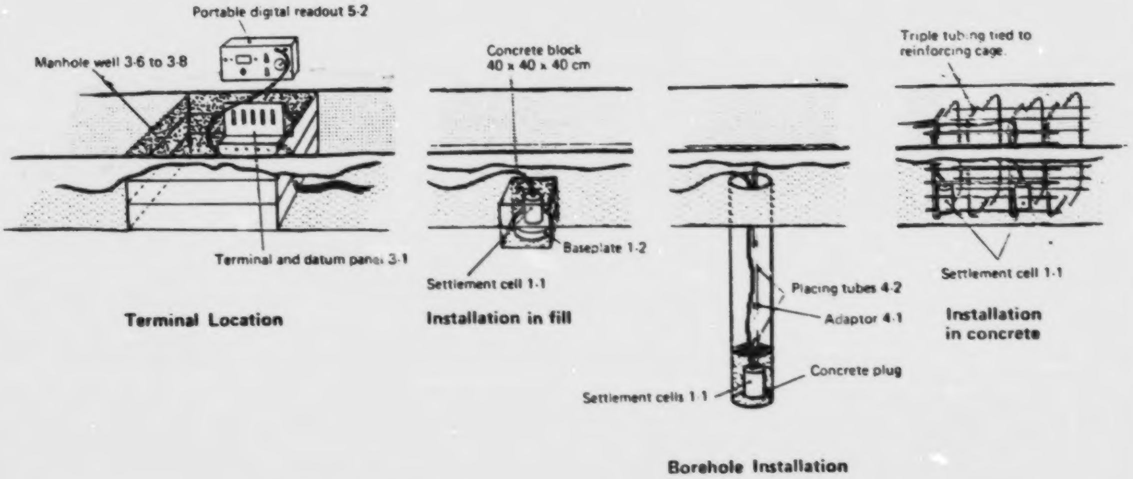
Triple tubing 2.1 is connected to the cell, allowing a length equal to the distance between cell and terminal panel plus 5% to accommodate movement. The pink mercury tube is connected to the filling reservoir. The cell bleed screw is loosened with the key provided, and mercury is poured into the reservoir using the funnel. A clean dish beneath the cell is used to catch mercury that may overflow. Clean mercury should be used: approximately 450g is required for every 10m of tubing. The reservoir may be raised to assist filling and should at no time be allowed to empty or air will be introduced. Filling generally takes about 30 minutes per 100 metres of tubing.

When mercury appears at the bleed screw the cell is rotated to allow all air to escape; the bleed screw is then closed. The functioning of the cell is checked by connecting the air lines to a portable readout. The tubing is then laid in the trench, placing the cell in its excavated pocket. Baseplate 1.2 may be fixed to the cell to assist in holding it in place. The other end of the mercury tube is then disconnected from the filling reservoir, and connected to a datum sight tube on the terminal panel. The syringe is used to adjust the level of mercury to the datum line. Sufficient concrete is placed beneath the cell to give the required initial reading, then the remainder of the pocket is backfilled with concrete. Tubing in the trench is colour-coded and snaked to allow for ground movement. It should be protected from mechanical damage by at least 15cm of stone-free sand or clay above and below. The trench is then backfilled using if possible the excavated material, free from large stones and at natural water content.

Installation in Boreholes and Cast in Concrete

The procedure for filling with mercury is identical to that described above. For borehole installations the hole should be not less than 90mm diameter. Concrete is placed to form a plug at the base of the hole. The cell is pushed into the concrete using 4.1 placing adaptor and 4.2 or 4.3 placing tubes. The installing equipment is disconnected from the cell and the hole backfilled with weak grout or granular material. Tubing should be kept taut and straight during the backfilling operation.

For installations in concrete the cells are generally secured to the reinforcement. The tubing is tied back at frequent intervals along its length, with care taken to avoid kinks or sudden bends. Readings of each cell are taken immediately prior to concreting as a final check that cells are correctly installed and are functioning as intended.



Terminal Location

Installation in fill

Borehole Installation

Installation in concrete

Specification

To order equipment please quote the data sheet and specification numbers, the name of the item and the quantity required, for example: 4S3.7 Manhole Surround, 15 No.

1. Settlement Cells

1.1 Pneumatic Settlement Cell comprising a pneumatic pressure transducer with a mercury chamber secured to its base. The transducer incorporates a viton rubber diaphragm in a stainless steel housing, with a left-hand threaded connection to receive 4.1 placing adaptor and with two brass connectors to fit the pneumatic lines in 2.1 triple tubing. The stainless steel mercury chamber is drilled and tapped to receive 1.2 baseplate, and has a stainless steel connector to fit the mercury line in 2.1 triple tubing. Tube connections are protected by a PVC cap and sealing gland. Overall dimensions 80mm o.d., 100mm long, weight 1.3kg. Operating range zero to 20m head of mercury, accuracy ± 1cm head.

1.2 Baseplate, optional for use with 1.1 settlement cell installed in fill or concrete. Comprising epoxy painted aluminium alloy disc 305mm o.d. 12mm thick, weight 1.85kg, complete with fixing screws.

2. Tubing and Accessories

2.1 Triple Tubing comprising three type 11 nylon tubes 1.9mm i.d., 3.2mm o.d., black, white and pink, sheathed with 1mm thick polythene. The pink tube is generally used as the mercury line, the black and white tubes for operating the pneumatic transducer of cell 1.1. Burst pressure 13MPa, minimum bending radius 30mm. Supplied in lengths up to 600m, weight 50g/m.

2.2 Straight Coupling, brass with two brass olives and nuts, for line to line connection of pneumatic lines in 2.1 triple tubing. Weight 10g.

2.3 Straight Coupling, stainless steel with two anti-friction washers, olives and nuts, for line to line connection of mercury line in 2.1 triple tubing. Weight 15g.

2.4 Olive and Nut, brass, spares for coupling 2.2.

2.5 Olive, Nut and Anti-Friction Washer, stainless steel, spares for coupling 2.3.

2.6 Quick-Release Couplings, brass, self-sealing, burst pressure 82MPa. Required for connection of tubing 2.1 direct to 5.1 or 5.2 pneumatic readout units. Supplied as one pair complete with dust caps. Total weight 150g.

2.7 Mercury, 3.17kg supplied in plastic bottle, sufficient to fill approximately 70m of mercury line in 2.1 triple tubing.

3. Terminal Equipment

3.1 Terminal and Datum Panel manufactured for 3-20 settlement cells. Including for each cell an adjustable mercury datum sight tube, a stainless steel mercury line connector, two brass bulkhead connectors and dust caps. The bulkhead connectors receive the two air lines from each cell and accept flying leads from 5.1 or 5.2 portable readout units. Mounted complete with tube ducting on a 30cm high panel. A panel for 10 cells is 50cm wide and weighs 4.6kg.

3.2 Switched Terminal and Datum Panel similar to 3.1 but allowing readings at each cell without re-connection of the readout lines. Comprising pneumatic delivery and return manifolds with one pair of 2.6 quick-release couplings to connect with 5.1 or 5.2 readout units, and for each cell a mercury datum sight tube, two shut-off valves, mercury line and air line connectors. Mounted complete with tube ducting on a 60cm high panel. A panel for 10 cells is 65cm wide and weighs 12.7kg.

3.3 Instrument House, timber, with door and window in one section, lockable timber flap to window. Flat roof protected by waterproof roofing felt. Timber floor on timber bearers, the whole unit fully lined with softboard insulation. External box for commercial gas bottle. Supplied in easily erected kit form, dimensions as required, all timber treated with preservative.

3.4 and 3.5 Instrument House Entry Ducts comprising 600mm long heavy gauge PVC flanged tube with cover plate, neoprene gasket and flange bolts. The cover plate incorporates individual brass and neoprene waterproof glands to take 2.1 sheathed triple tube. The entry duct is usually set in concrete in the floor or wall of an instrument house, tubing passing through the duct to terminal panel 3.1 or 3.2. Dimensions as tabulated.

Catalogue No.	3.4	3.5
i.d. (mm)	100	150
o.d. (mm)	115	168
No. of triple tube glands	5	10
No. of settlement cells	5	10
Weight (kg)	3.4	6.8

3.6 Manhole Well Unit, comprising individual pre-cast concrete open-ended box 600 x 450mm internal dimensions, 50mm thick, 150mm high, weight 42kg. Tongued and rebated for stacking to give any required well depth and to receive 3.7 surround.

3.7 Manhole Surround, pre-cast concrete to fit well units 3.6 and to receive 3.8 steel cover and frame. Weight 25kg.

3.8 Manhole Cover and Frame, galvanized steel, to fit 3.7 manhole surround or for casting direct in concrete, complete with two lifting keys. Overall weight 8.2kg. Designed for 2500kg surface loading, heavier designs available.

4. Installing Equipment

4.1 Placing Adaptor for installing 1.1 settlement cells in boreholes. Comprising cadmium-plated mild steel tool with left-hand thread to suit pneumatic settlement cell, the other end threaded to fit placing tubes 4.2 or 4.3. Overall length 120mm, weight 300g.

4.2 Placing Tubes, 12mm i.d. galvanized mild steel supplied in 3m lengths, threaded each end with one threaded coupling. To suit placing adaptor 4.1. Weight 4kg per 3m length.

4.3 Placing Tubes, 12mm i.d. heavy gauge rigid PVC, supplied in 3m lengths threaded each end with one threaded coupling. To suit placing adaptor 4.1. Weight 800g per 3m length.

4.4 Tool Kit for installing pneumatic settlement cells. Including four spanners for tube connections, tube cutting knife, pliers, two bleed screw keys, mercury filling reservoir and funnel, syringe and injection tube, all in a steel toolbox. Overall weight 3.2kg.

4.5 Coloured Adhesive Tapes, 9mm width, set of 10 reels 20m long in assorted colours. One set suitable for marking up to 5000m of settlement cell tubing.

5. Readout Equipment

5.1 Portable Meter Pneumatic Readout including a 150mm dia Bourdon test gauge, return flow indicator and gas reservoir bottle recharging from external air or nitrogen supply or in an emergency by foot pump. Housed in epoxy resin coated steel case with lid and carrying handle. Overall dimensions 43 x 23 x 20cm, weight 12.3kg, fitted with quick-release sockets to take fly leads for connecting to 3.1 or 3.2 terminal panels. Gauge calibration zero to 200 cm of mercury, precision ± 1cm head.

5.2 Portable Digital Pneumatic Readout including an electric pressure transducer, digital display, rechargeable nickel-cadmium battery, gas reservoir bottle recharging from external nitrogen or air supply or in an emergency by foot pump. Housed in epoxy resin coated steel case with lid and carrying handle. Overall dimensions 43 x 23 x 20cm, weight 12.7kg, fitted with quick-release sockets to take fly leads for connecting to 3.1 or 3.2 terminal panels. Range switch selects alternative displays from zero to 19.99m head of mercury, 199.9m head of water, 19.99 kgf/cm^2 or 199.9lbf/in^2. Hysteresis, non-linearity and drift less than 0.2% full scale. Battery life minimum of 10 hours between charges. Complete with charger for either 240v 50Hz or 120v 60Hz supply.

5.3 Gas Pressure Regulator for recharging readout 5.1 or 5.2. Comprising regulator valve and pressure indicator zero to 160 bar (recharge pressure 60 bar), with connector to fit ⅝in. BSP outlet on U.K. type air or nitrogen cylinder, and with coupling to receive recharge hose from the readout unit.

THE MK III DIGITAL PNEUMATIC READOUT

The MK III Digital Pneumatic Readout provides the following facilities not included in the MK II design.

(I) Control of Applied Pressure at the Installed Instrument

The pneumatic arrangement ensures that pressure is applied at a controlled rate of increase, regardless of tubing length.

This minimises volume change at the installed instrument by preventing overpressurisation from source and by allowing time for the return line to vent any excessive pressure. Thus the instrument is disturbed as little as possible during the reading cycle. This results in greater reading accuracy.

(II) Automatic Pressure Cut-Off on Sensing Return Flow from the Installed Instrument

The pneumatic circuit ensures that as soon as return flow from the installed instrument is sensed, the pressure applied to the send line is automatically shut off whereupon the reading sequence is concluded without assistance from the operator.

Since the reading sequence is now automatic:

(a) Operator error is eliminated since each sequence is identical to its predecessor. Repeatability and accuracy are thus improved.

(b) The method makes more economical use of the pressurised gas source enabling more readings to be taken from each charged cylinder.

(III) The Check Calibration Facility

The MK III readout is fitted with a Check Calibration Facility enabling possible small changes in amplifier performance to be detected, quantified and corrected at each reading.

Limitations

The MK III Digital Pneumatic Readout is limited to a maximum operating pressure of 200 PSI (equivalent to approximately 140 m/H_2O, 10.3 m/Hg).

The Slope Indicator Company's Liquid Settlement Systems are designed to measure and monitor subsidence in areas inaccessible during construction to standard surveying techniques. The basic operating principle of the Settlement System is to measure elevation changes between two points which are connected by a flexible liquid column. The uppermost point of the liquid column, normally mounted outside the monitored area, is a reservoir which acts as a fixed reference level. At the lower end of the liquid column is a pressure transducer which senses liquid head change caused by the vertical distance between the two end points.

These systems are ideally suited for both the project engineer and contractor, enabling settlement data to be gathered frequently, without major slowdowns and interruptions from survey crews, or damaged settlement pipe.

Shipped ready to install, complete with transducer tubing, reservoir and fittings attached, they are available with either pneumatic or vibrating wire transducers. System configurations are dependent on transducer's range, resolution, and accuracy.

DESCRIPTION

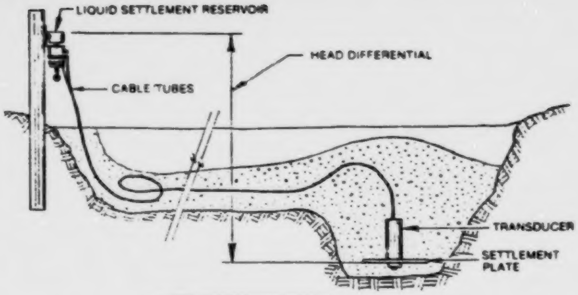
Pneumatic Transducers

Model 514163 is a low displacement pneumatic transducer. The transducer senses the pneumatic pressure needed to balance a flexible diaphragm which is in contact with the liquid column. The Transducer utilizes a five-tube tubing; three pneumatic tubes and two liquid column tubes.

A settlement measurement is taken by applying gas pressure to the input tube, through the balancing chamber and into the output tube which is connected to a portable indicator containing a high precision pressure gauge. Gas pressure in the chamber and the two tubes increases until it equals the pressure of the liquid column. At equalization, a valve in the transducer opens the third pneumatic tube enabling any excess pressure to vent to atmosphere.

The three-tube measuring method increases accuracy by eliminating over-registration of pressure caused by long tube lengths and higher operating pressures. After equalization, the pressure changes within the balancing chamber will be shown accurately on the high precision output gauge since there is no flow in the interconnecting pneumatic tube.

The Model 514163 can also be operated with two pneumatic tubes. This configuration saves material costs by eliminating the output tube. In this case the high precision pressure gauge is connected in-line with the input tube to measure the pressure to the transducer.



The difference between the actual balancing chamber pressure and input pressure, increases with the longer tube lengths and higher operating pressures. However, as long as tubing lengths are not added, repeatable operating procedures maintained, and settlements not too extreme, the same precision may be achieved.

Both systems measure pressure relative to the elevation of the liquid column; approximately 1 psi per 2.3 feet, with a maximum elevation differential of 250 feet and a minimum head requirement of approximately 10 feet.

Model 51483 is a pneumatic amplifying transducer. Its amplification is achieved by incorporating two flexible diaphragms within the same cavity, one larger than the other, to balance the pneumatic pressure against the liquid column pressure. The transducer utilizes a five-tube tubing; three pneumatic and two liquid column tubes.

A settlement measurement is taken by applying pressure to the input tube. The input pressure is measured by an in-line high precision pressure gauge. The flow enters and pressurizes the balancing chamber which contains one of the two diaphragms within the chamber. Any excess pressure is vented through the second tube. The third tube is unpressurized and connected to an equalizing chamber that separates the two flexible diaphragms to compensate for changes.

The 51483 Transducer produces an amplification ratio of approximately 23 to 1, or equivalent to 10 psi per 1 foot.

The maximum elevation difference between transducer and reservoir is 20 feet and a minimum elevation requirement of approximately 3 feet. The output pressure gauge incorporated within the portable pneumatic readout, which operates the pneumatic settlement transducers, establishes the system's overall range and accuracy.

Vibrating Wire Transducer

Model 52683 is an electrical vibrating wire pressure transducer. The wire and pickup of the vibrating wire transducer are enclosed within a cavity with one end of the wire fixed to a thin flexible stainless steel diaphragm. Flexure of the diaphragm, due to the difference between external and internal pressures caused by the liquid column, changes the tension in the wire, thus changing the resonant frequency. The transducer utilizes four tubes; two pneumatic tubes, two liquid column tubes and a two conductor cable.

The Transducer is capable of zero check as well as calibration check while in-place. A Buna-N membrane separates the external pressure from the perforated stainless steel diaphragm. When back pressure in excess of the external pressure, caused by the liquid column, is applied to the vent tubes, the membrane will separate from the stainless steel diaphragm and leave it unstressed. Each transducer is also provided with transient overvoltage protection.

The transducer frequency, when monitored with Slope Indicator Company's Vibrating Wire Indicator Model 52669, can be displayed as the period of natural resonance in the period mode, or as micro-strain which is proportional to pressure in the strain mode. The Vibrating Wire Settlement System has a resolution of 0.1 microsecond, corresponding to 0.1 inch of head differential. The maximum elevation differential between transducer and reservoir is 25 feet.

Tubing

All of the settlement systems use a two-tube liquid column design. This enables easy flushing should air or dirt accidentally enter the liquid column after the system is in place. The actual tubing configuration is decided upon by the type and style of transducer selected. All pneumatic and liquid tubes are made of extra heavy walled polyethylene for added strength and color coded for easy identification. The electrical cable which is incorporated into the tubing bundle for operation of the vibrating wire transducer, is a two-conductor tinned copper stranded wire, color coded with a polypropylene insulation and an aluminum-polyester shield totally jacketed in PVC (Poly Vinyl Chloride). All tubing and wire configurations are completely jacketed in low density polyethylene for added protection and ease of handling.

Reservoir

Each system requires a reservoir at one end of the liquid column opposite the pressure transducer. The reservoir incorporates a pressure actuator to compensate for temperature and atmospheric pressure changes to the system during transportation. Once the system is installed, the reservoir is opened to atmosphere relieving the actuator, and the liquid level adjusted to give a measureable and repeatable reference level to the liquid column for the pressure transducer to measure.

INSTALLATION

All systems are shipped ready to install, this helps reduce contractor down-time and overall installation time.

The typical installation for the settlement system is within a protective trench. The size of the trench is dependent upon the surrounding material and the number of units to be installed. The trench is cut outward from the area where the transducer will be placed, to an area outside the construction zone. A bed of sand is placed in the bottom of the trench for tubing support and protection. At the outer end of the trench a vertical post for the attachment of the reservoir is installed. The reservoir is normally placed at the minimum settlement range for the transducer installed. The post and reservoir act as a reference level and readout location for the settlement system. Prior to backfilling the trench, the system is activated and the transducer and reservoir elevations determined to assure proper functioning. Once the system is verified operational, the trench can be backfilled.

Since these are scientific instruments, measurements should be taken, recorded and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of such personnel.

SPECIFICATIONS

MODEL	51483	514163	52683
Settlement Range:	3-20 ft (1-6 m)	10-250 ft (3-76 m)	18-300 in (450-7600 mm)
Pressure Range:	30-200 psi (206-1400 kPa)	5-300 psi (35-2000 kPa)	0-12 psi (0-85 kPa)
Sensitivity $\frac{\text{Output}}{\text{Input}}$:	0.79 psi/in (0.21 kPa/mm)	0.04 psi/in (0.01 kPa/mm)	0.1 ms/0.1 in (.04 ms/mm)
Repeatability:	±0.1 inch (±3.2 mm)	±0.2 inch (±6.4 mm)	±0.1 inch (±2.5 mm)
Weight:	4 lbs (1.8 kg)	3 lbs (1.4 kg)	7 lbs (3.2 kg)
Dimensions:	7.75" H x 3.75" Dia. (197 x 95 mm)	7.25" H x 2.75" Dia. (184 x 70 mm)	12" H x 3.75" Dia. (305 x 95 mm)
Tubing Configuration:	5 tube: 3 pneumatic/2 liquid	5-tube or 4 tube: 3 or 2 pneumatic/2 liquid	4-tube/1-cable: cable/ 2 atmosphere vent/2 liquid

Sinco
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TWX 910 [illegible] SINCO SEA, Cable SINCO SEA Phone (206) 633-3073

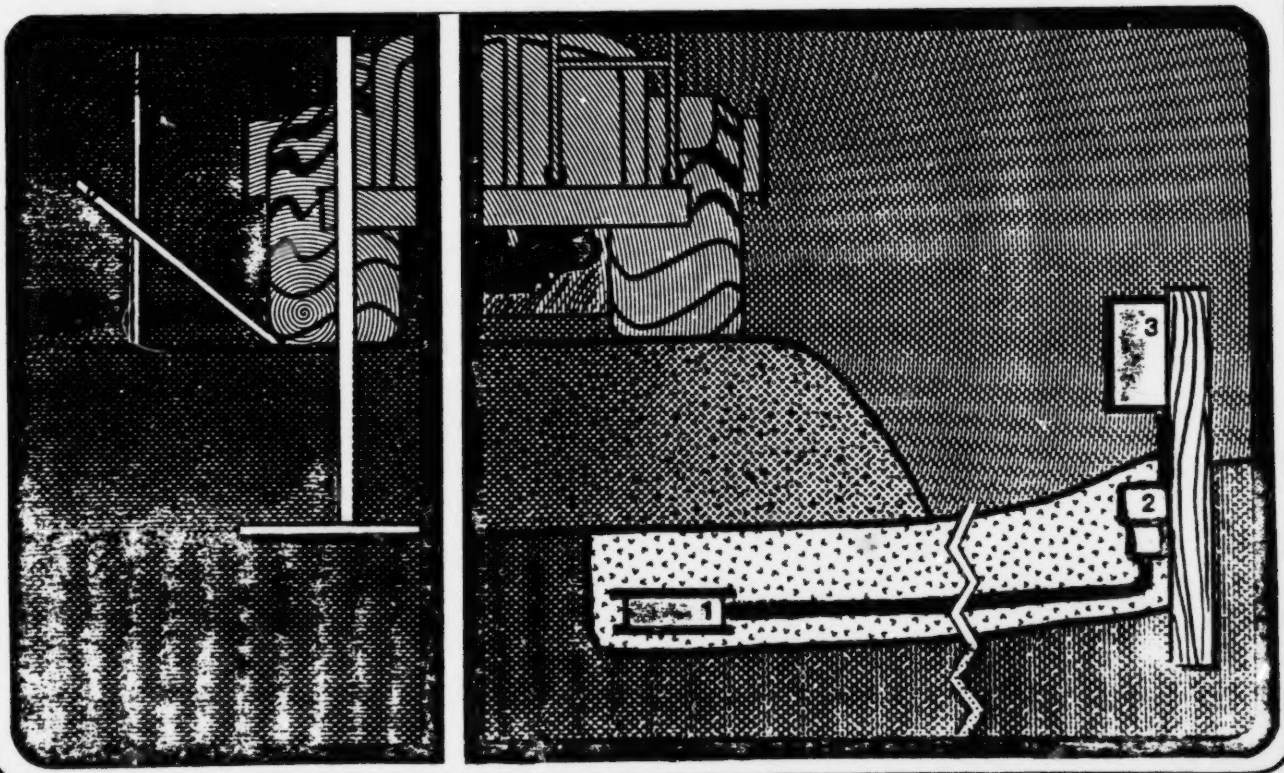
PETUR®

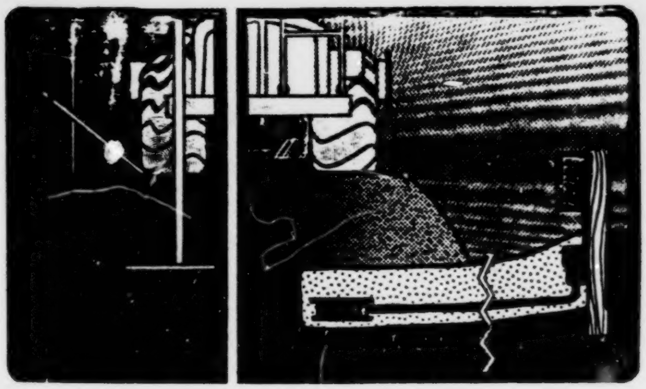
SETTLEMENT SYSTEMS

While eliminating many costs and delays for both the engineer and contractor, PETUR monitoring systems greatly increase the reliability of the data. Exclusive readout techniques are provided—even continuous recording.

Standpipes slow the progress of earthfill work, are easily damaged.

PETUR sensors (1) leave site free of obstructions. Reservoirs (2) and readout stations (3) provide remote (up to 1000ft) multiple data gathering capability using portable instruments.





Users report major cost savings.

In a typical instance, an Ohio contractor had allowed $135,000 for direct cost of facilities for settlement monitoring at 100 different points on a site, based on the use of settlement plates and standpipes. PETUR systems were substituted, including 100 sensors and four readout stations, at an equipment cost of $26,000 and reported installation cost of $30,000, for a direct saving of nearly $80,000.

Indirect savings may well prove more significant still, in terms of ultimate project cost. Because all monitoring equipment and procedures are located away from the active work area, coordination problems and delays are eliminated. Contractor personnel are freed-up to expedite the progress of the job without having constantly to take special precautions for steering clear of standpipes and for hand-filling the areas around them.

The benefits of *both* direct and indirect costs savings are usually obtained.

This ability to help shorten completion time, whether a project is large or small, can greatly benefit users of PETUR systems.

Engineering cost savings are substantial. Tremendous savings in personnel time for collecting, computing and rechecking data can be realized, both in the field and at the office. Eliminating difficult and unpredictable working conditions frees staff energies for concentrating on careful evaluation of the data.

PETUR systems offer the soils engineer important advances in range and accuracy. The system ranges and accuracies listed here (see table) together with system capability for monitoring at distances of up to 1000 feet (305m) have opened up new application possibilities and advanced techniques not approached by systems previously available.

The PETUR system concept and operating principle:

The PETUR system monitors settlement or heave simply by indicating any changes in elevation at one end of a column of liquid. The upper end of the column is a *reservoir* which acts as a fixed reference level. The main body of the column is interconnecting, flexible liquid-filled *tubing*. The lower end of the column is the *sensor* which indicates any pressure changes caused by vertical movement at its point of location.

The system components are factory-assembled as a *Sensing Circuit Assembly*—pre-filled with water (or water plus anti-freeze). A description of the components follows:

☐ *The Sensor:* This transducer, placed underground in the area of anticipated settlement or heave, contains the lower end of the liquid column—the upper end of which is the fixed reference level in the reservoir. The elevation difference between sensor and reservoir creates a liquid pressure at the sensor which governs, and is balanced by, an opposing pneumatic pressure in the control/readout circuit. Any change in elevation of the bottom of the liquid column is thus exactly reflected by a pneumatic pressure change transmitted through the tubing bundle to the readout and control instruments located at the readout station.

☐ *The Tubing:* Flexible tubing connects the sensor with the reservoir, to provide the main body of the liquid column. The tubing bundle consists of two liquid-filled tubes and two pneumatic circuit tubes, all contained within one protective PVC jacket. The double, liquid-filled tubes actually form a single U-tube which can easily be flushed and re-filled, even after burial, in the unlikely event that air entrapment in the system is suspected.

☐ *The Reservoir:* The reservoir is located at the readout station, away from the area of anticipated settlement. It is permanently mounted to provide a fixed reference level. Along with the entire assembly, it is filled at the factory, and its design prevents evaporation and compensates for temperature changes.

When portable *readout and control instruments* are connected to the sensing circuit assembly, the control/readout circuit is completed, ready for data gathering. Following is a description of these instruments:

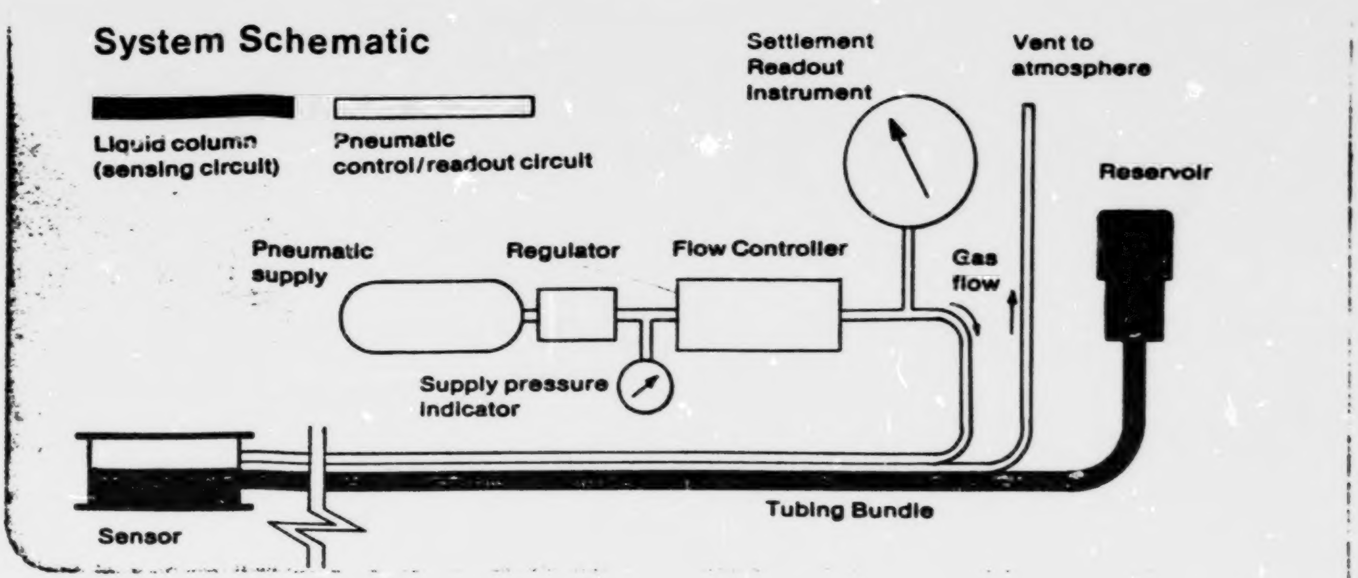
☐ *The Readout and Control Instruments:* These are a pair of instruments which attach by quick couplings to the control/readout circuit; the point of connection is the readout station, where the tubing bundle terminates. The instruments are light weight, portable and completely self-contained, providing both the pneumatic controls and the readout data for as many sensing circuit assemblies as

System ranges & accuracies

SYSTEM MODEL NUMBER	SYSTEM RANGE FT (M)	SYSTEM ACCURACY ±FT (M)	SENSOR MODEL NUMBER
SS-106	10.4 (3.20)	0.01 (.003)	SP-105
SS-107	23.3 (7.10)	0.02 (.006)	SP-105
SS-108	35.7 (10.88)	0.05 (.015)	SP-105
SS-109	46.0 (14.02)	0.05 (.015)	SP-105
SS-110	69.0 (21.03)	0.10 (.030)	SP-105
SS-111	103.5 (31.55)	0.10 (.030)	SP-105

Note that *system range* as listed is a maximum value for the elevation difference between sensor and reservoir; actual elevation difference may be any value from 0.5ft (.15m) to 103.5ft (31.55m), depending on system model number specified.

System Schematic



may be required at any particular job site. An easily replenished supply of compressed dry nitrogen or carbon dioxide is incorporated, to provide the pneumatic source for pressurizing the control/readout circuit.

☐ *The key control element is the PETUR flow controller*, a unique, patented device of great simplicity which is ultimately responsible both for accuracy and for the ability to monitor conditions at the sensor *continuously*. It has these two critically essential functions: *first* to provide a constant rate of gas flow so that a null-balance condition is maintained at the sensor; *second* to allow maintenance of the flow rate at an extremely low level (35cc/min)—which prevents pressure distortions that could otherwise result from restrictions in the tubing (occuring accidentally at installation or afterward).

Readout is easy and fast—even automatic. Earlier-type instrument systems, lacking the simplicity of operation just described, typically impose substantial limitations on data collection. Each reading represents a discrete event set up within the remote sensor, requiring that an operating cycle be initiated and carried out by the technician or engineer.

The PETUR system readout relies instead on a continuous dynamic balance between the liquid pressure in the sensing circuit and the pneumatic pressure in the control/readout circuit—a balance which the latter circuit *automatically* maintains. Personnel need only connect the instruments and record data.

Thus data gathering is much easier, faster. It also becomes evident why *continuous automatic settlement recording* is a natural and compatible PETUR option. Opportunities are thus opened up for handling difficult and exacting project requirements under any soil conditions.

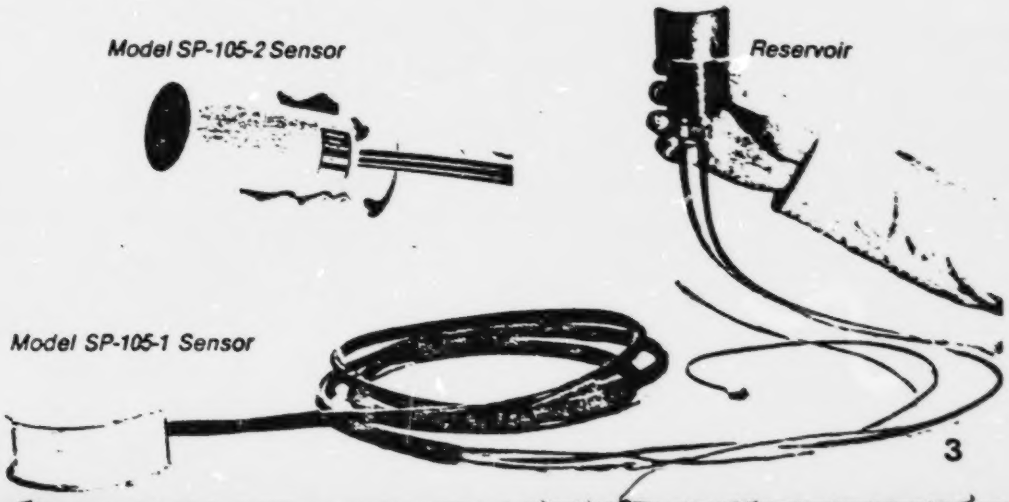
Superior accuracy is inherent in the PETUR operating concept. The key to the PETUR concept is the automatic maintenance of a steady-state condition within the system. By contrast, the mercury-filled sensing circuit of a conventional system is in a state of interrupted flow at the moment of readout. The resulting data are thus instantaneous values, based on transient conditions which tend to impair accuracy by introducing unpredictable variables. For example, speed of closing of a check valve in a conventional system's control circuit will affect the readout value.

Steady, balanced conditions in the PETUR circuits leave virtually nothing to chance. This is the assurance of reliable, repeatable accuracy.

Use of a water column, in place of mercury, has been a major factor in overcoming the limitations of remote settlement sensing. See Technical Footnote on back cover.

SENSING CIRCUIT ASSEMBLIES

— consist of sensor and reservoir with an interconnecting tubing bundle. Model SP-105-1 sensor is shown with this sample assembly, and is for system ranges to 35.7ft (10.88m); Model SP-105-2 sensor is used for system ranges to 103.5ft (31.55m).

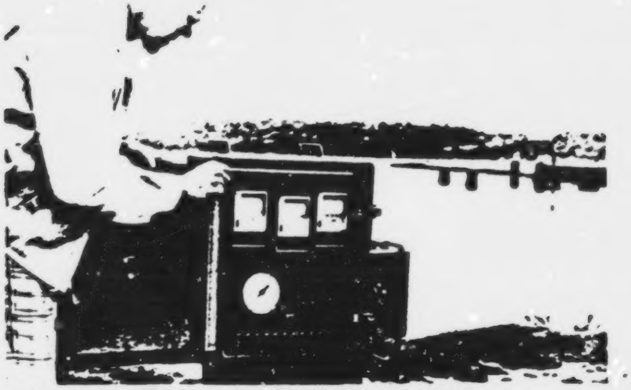


Varied readout and control options fit the needs of individual users.

Settlement readout instrumentation is most often supplied as an auxiliary gauge or auxiliary manometer, to avoid duplication of control equipment used with other geotechnical systems such as piezometers. Thus the settlement readout instrument is paired with a separate control/readout unit, with the latter providing the regulated pneumatic pressure source.

In each section below, the unit listed first is the one best suited to acquiring larger amounts of data, where speed and convenience are a main concern. *One unit from each section (settlement readout and control/readout) is required.*

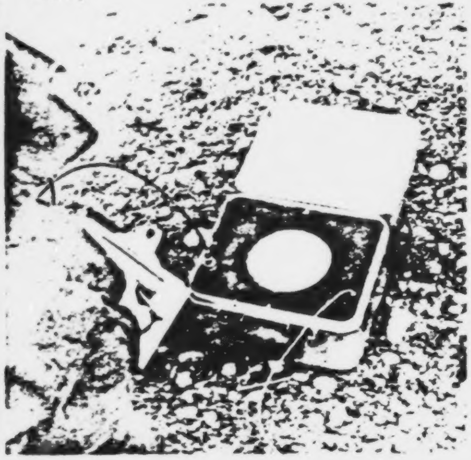
All these PETUR instrument options assure the user of ☐ extremely high accuracy and repeatability; ☐ freedom from excessive weight and bulk for ease in carrying and handling; ☐ durable construction for continuing reliability.



FOR APPLICATIONS WHERE CONTINUOUS AUTOMATIC DATA RECORDING CAN FILL AN IMPORTANT NEED: This exclusive PETUR geotechnical readout option can be an indispensible tool in dealing with large projects involving exceptionally unstable soil conditions, and for other unusual applications. Automatic continuous data recording equipment is custom designed; inquiries are welcomed.

SETTLEMENT READOUT AUXILIARY INSTRUMENTS

MODEL SC-100 (*below*) incorporates a premium-quality double-rotation gauge of large size. Diameter is 6in(15cm) with scale length of 30in(76cm). It provides accuracy and sensitivity of ± 0.1% of full scale. (See photo p.5, upper right, for typical use with C-102 control/readout unit.)



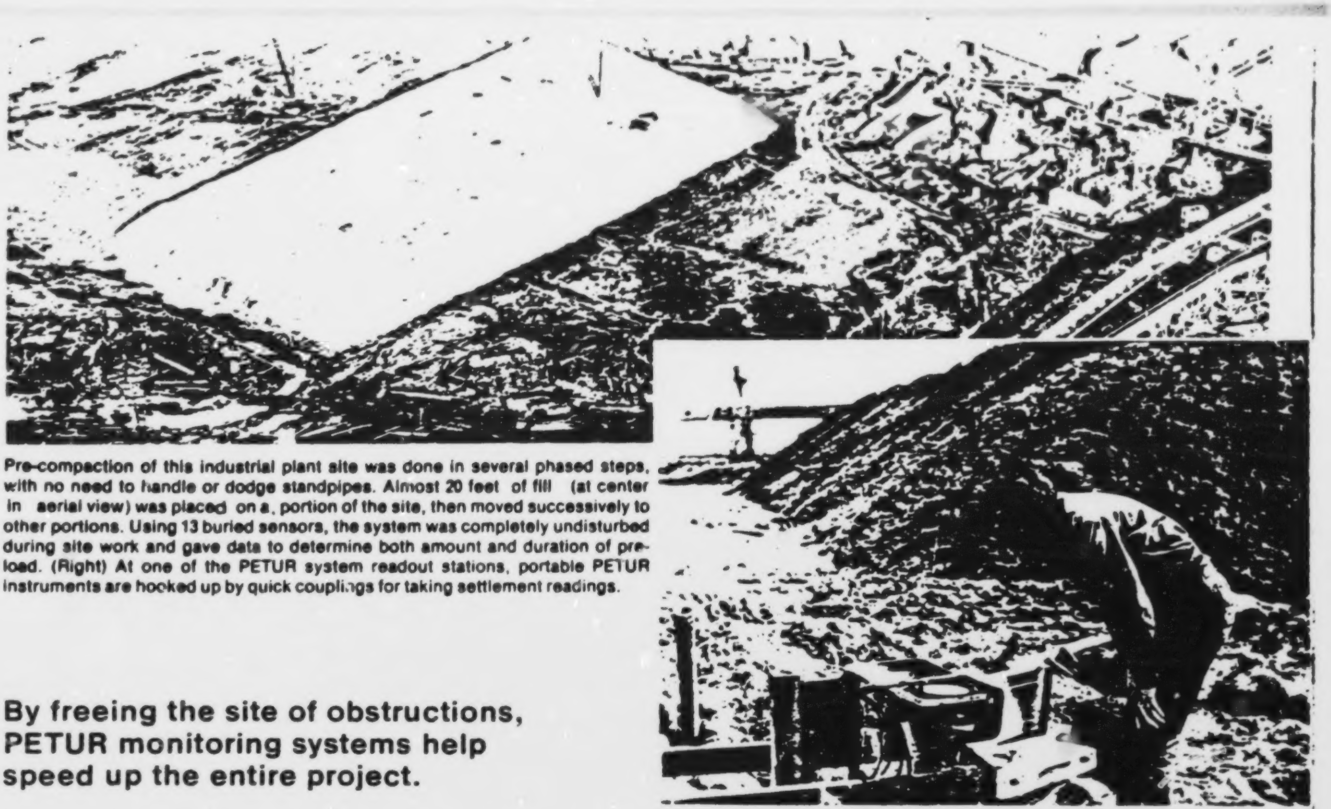
MODEL NUMBER	INSTRUMENT RANGE* FT (M)	INSTRUMENT READABILITY* IN (M)
SC-100	10.4 (3.17)	0.2 (.005)
	23.3 (7.10)	0.5 (.013)
	***Special ranges:*	
	35.7 (10.88)	0.5 (.013)
	46.0 (14.02)	1.0 (.025)
	69.0 (21.03)	1.0 (.025)
	103.5 (31.55)	2.0 (.051)

(*) *Range* is elevation difference which produces full-scale readout; *readability* is smallest incremental scale unit. (**) *Special ranges* require longer delivery time.

CONTROL/READOUT INSTRUMENTS

with regulated pneumatic pressure source

MODEL C-102 *(left)* has a convenient internal-tank pressure source which needs only minimal attention. For settlement readouts, either auxiliary instrument listed above may be connected; the built-in gauge (selected from the PETUR price list or other literature) gives readouts from other geotechnical systems such as PETUR piezometers.



Pre-compaction of this industrial plant site was done in several phased steps, with no need to handle or dodge standpipes. Almost 20 feet of fill (at center in aerial view) was placed on a portion of the site, then moved successively to other portions. Using 13 buried sensors, the system was completely undisturbed during site work and gave data to determine both amount and duration of preload. (Right) At one of the PETUR system readout stations, portable PETUR instruments are hooked up by quick couplings for taking settlement readings.

By freeing the site of obstructions, PETUR monitoring systems help speed up the entire project.

PETUR settlement systems' rapid acceptance has been due to their success in taking the place of line-of-sight leveling. In doing this they have completely changed the role of instrumentation— which previously was limited by the high cost and uncertain reliability of mercury-filled equipment.

With the elimination of mercury, the idea of using an instrument system was no longer a last resort, to fall back upon only where a site was impossible for optical methods. Instead, PETUR systems made it practicable to replace laborious survey work for *all* settlement monitoring.

Completely eliminating the 'obstacle courses' created by standpipes became a practical reality, along with better engineering data at much lower cost.

An end to worries about damaged equipment. Even with constant work-delaying attention by contractor personnel, damage to standpipes does happen. Typically this means still further delay, and even loss of irreplaceable data.

A PETUR system gets all equipment safely out of the way, located either remotely or underground. In the event of accidental damage during installation, there's a further exclusive safeguard: repairs are easy. And, entry of contaminants is not a concern as the whole system can be remotely flushed, including components and tubing already underground.

Now: less time needed by engineering and contractor personnel. In contrast to the difficult conditions often faced by survey crews when trying to collect standpipe data, the PETUR systems provide direct readouts—in minutes rather than hours—any time, day or night, in any weather—without interrupting contractors' work.

Freedom from lengthy office calculations is a further vital saving of time and cost, especially through avoiding errors and re-surveys. PETUR system data is instantly rechecked, on site. Correct functioning of all components—even buried components—is readily verified at any time.

Getting larger amounts of settlement data, and getting it as frequently as it's wanted, has become a practical reality through the PETUR systems' ability to make life simpler for engineering and contractor personnel. Then there's the ultimate in both performance and time saving: *continuous automatic data recording*, a totally unique PETUR option (page 4).

A damaged standpipe like this can happen despite the best efforts of equipment operators to steer clear. Using a PETUR system for settlement monitoring here would leave the site as free of obstructions as the one pictured above.

tion, and for supervision and training of customer's staff. PETUR field engineer, right, explains system operation and the pneumatic connections at this readout station. Trench at bottom has yet to be filled.

System installation is simple.

All permanent connections are factory-assembled, so installing a PETUR settlement monitoring system is extremely easy. Laying the complete assemblies in place at the desired locations, and providing some protective covering for the tubing runs and terminations, is all it takes.

Normal installation calls for ditch burial of each sensing circuit assembly, and only two small tubing leads need to extend above ground at the readout station site. This gives maximum physical protection and temperature stability. (If concrete or rock prevents trenching, the runs should be protected in pipes or similar enclosures.) In cold weather, burial should be sufficiently deep to prevent freezing; if severe climate makes this impracticable, antifreeze solution is available.

Following are the general instructions for installation:

☐ **Place the sensor** in its required location.

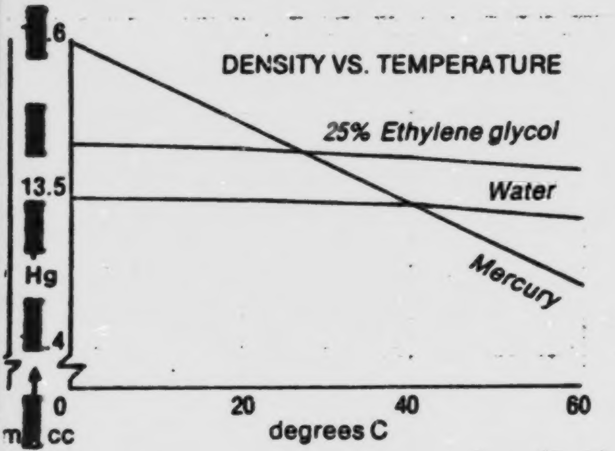
☐ **Lay the tubing** in a protective trench running between the sensor and readout locations. The trench should be at least 18in (46cm) deep, or more if heavy equipment will be operating above it.

☐ **Place a vertical post** at the readout location. Strap the reservoir in a vertical position at the base of the post in the trench (elevation needs to be at least six inches above the sensor).

☐ **Lead the two pneumatic tubes** past the reservoir and up the post so they will be above final ground level. Protect the ends of the tubes so that water or dirt cannot enter. Use of a protective housing such as a wooden or metal box or capped pipe is recommended (see installation photos).

☐ **Check out the installation** by connecting the system to the readout instrument and following the operating instructions.

☐ **Backfill the trench** with fine, granular material.



Technical footnote on the use of water rather than mercury in these advanced systems:

Earlier-type pneumatic-control monitoring concepts have required a heavy medium in the sensing circuit, to give the relatively large forces and pressures needed to counteract and minimize the effects of inherent operating errors. Mercury has been the universal choice for this purpose.

It has been through a marked advancement in pneumatic control concepts that PETUR systems are able to use plain water instead of mercury. (An antifreeze solution is used for the rare application where freezing conditions extend far underground.)

Among the benefits of using water are:

☐ *Ample volumetric stability* within the temperature ranges experienced under field conditions. See chart above.

☐ *Greater operating ranges* available to the user. Lower density of the liquid enables greater elevation differences and longer-distance remote sensing—without forces and pressures of impracticably large magnitude (which can actually cause rupture of mercury-filled systems where the limitations are overlooked).

☐ *Large cost savings* in comparison with mercury—which has become a semi-precious metal through ever-steepening cost increases.

☐ *Further large cost savings* by avoiding the need for expensive materials, which are required for use with mercury to withstand its highly corrosive properties and the mechanical stresses imposed by its great weight.

☐ *Elimination of toxic hazards* to personnel and the environment, created whenever mercury escapes as a result of failure of some system component.

How to order

(a) Settlement readout auxiliary instrument and control/readout instrument: specify model number(s) from page 4, indicating instrument range required.

(b) Sensing circuit assemblies: specify—

☐ The number of assemblies required;

☐ The system model number for each assembly (selected from range/accuracy table on p.2);

☐ Length of the tubing run for each assembly, including an extra 10% for slack (5% for the portion of any run beyond 250ft (76m));

☐ If weather will be sub-freezing, advise minimum ambient temperature anticipated.

(c) Protective housings for circuit terminations: If it's desired that these be factory-supplied, specify the number of readout stations and the number of circuits terminating at each station.

(d) Special requirements: Please describe so a quotation may be prepared.

PETUR®

For prices and warranty contact

PETUR INSTRUMENTS LTD.
No. 18-1780 McLean Ave.
Port Coquitlam, B.C., Canada V3C 1M9
Telephone (604) 941-4848

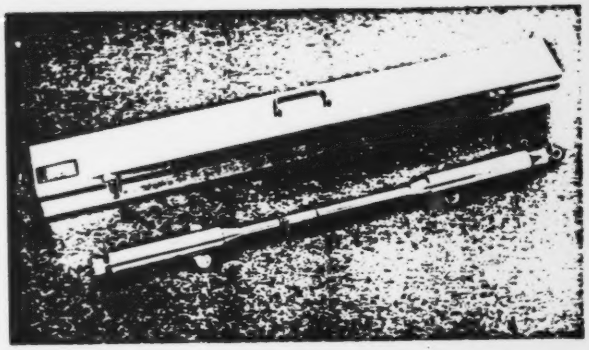
PETUR INSTRUMENTS LTD.
42 Queen Street, Box 308
Sutton, Ontario, Canada L0E 1R0
Telephone (416) 722-8356

The Horizontal Digitilt Inclinometer Sensor, Model 50329, provides precise data for determining vertical heave or settlement in embankments, dams, and foundations. This sensor operates in 3.38-inch O.D. Slope Indicator Casing, which is laid in place during fill operations or installed in boreholes. To allow for spread in embankments or fills, telescoping casing is normally used. Settlement rings or plates can be installed around plastic casing to permit lateral measurements with Sondex Ring Detector, Model 50812, attached to the Digitilt sensor.

The basic system consists of the permanently installed horizontal casing with a pull cable arrangement and the portable instrument. When the casing is accessible only at one end, a special dead-end pulley assembly for the stainless steel pull cable is used. The pull cable returns via a separate cable return pipe placed next to the inclinometer casing. Continuous loop or reel operation of the pull cable may be chosen. The portable instrument consists of sensor (probe) Model 50329, electrical cable marked in either English or Metric increments, and a Digitilt readout indicator.

Sensor: The uniaxial sensor, Model 50329, has a servo-accelerometer, in a water-proof housing, mounted in the same axis as the tracking wheels which ride in the casing grooves.

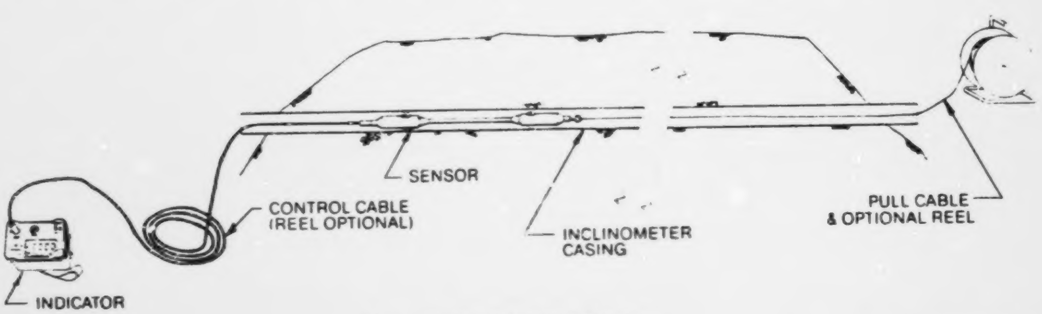
Indicator: The Model 50309 Digitilt LCD Indicator is a portable, battery powered indicator featuring a 4½-digit Liquid Crystal Display (LCD) and environmental construction for manually recording data in adverse field conditions. The Model 50308 Mag-Tape and Model 50368 RPP (Recorder-Processor-Printer) can also be used with this system.



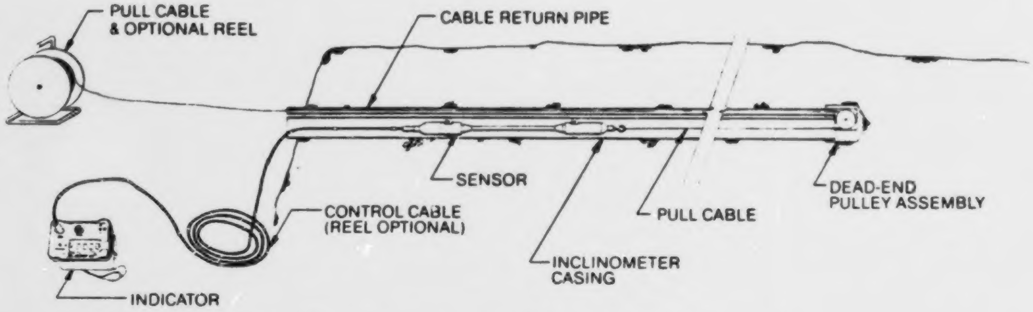
Electrical Cable: The sensor and indicator are connected with a 0.42-inch (10.7mm) diameter cable which carries power and signal. The cable has a stranded steel core to bear pulling stresses and eliminate connector and wire breakage; a heavy waterproof neoprene jacket; and external markings at one-foot or half-meter intervals for easy depth determination.

Casing: The grooved Slope Indicator Inclinometer Casing guides the wheels of the sensor in the direction of measurement and controls sensor orientation in a near vertical position. 3.38-inch O.D. aluminum casing or 3.34-inch O.D. plastic casing can be used with the Model 50329 Horizontal Digitilt Sensor.

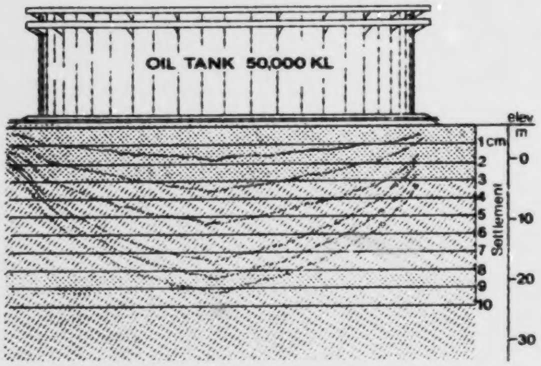
Dead-End Pulley Assembly: Special dead-end pulley assemblies or push rods are available for use with the Horizontal Digitilt Sensor System.



Horizontal Inclinometer System


PULL CABLE & OPTIONAL REEL
CABLE RETURN PIPE
SENSOR
CONTROL CABLE (REEL OPTIONAL)
PULL CABLE
DEAD-END PULLEY ASSEMBLY
INCLINOMETER CASING
INDICATOR

Horizontal Inclinometer System with Dead-End Pulley Assembly


OIL TANK 50,000 KL
elev m
1cm
2
3
4
5
6
7
8
9
10
Settlement
0
10
20
30

Schematic Illustration of Sub-Soil Deformation for Tank Load Measured by Horizontal Inclinometer

Recording and analyzing data is similar to standard Digitilt data. Data should be recorded for two opposite directions to eliminate zero errors caused by either the sensor or the indicator. To read the opposite direction, the sensor must be turned end for end.

Since this is a scientific instrument, measurements should be taken, recorded and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of such personnel.

Sensor Specifications:	**English (E)**	**Metric (M)**
Operating Range	± 35°	± 53°
Accuracy	± 0.1 inch per 100 feet of casing	± 2.5 mm per 30 m of casing
Sensitivity	1:10,000	1:20,000
Temperature Range	0° F to 120° F	-18° C to +49° C
Wheel Base	2.0 feet	0.5 M
Sensing Element	Servo-Accelerometer	Same
Dimensions	2.0" OD x 35.5" long	50.8mm OD x 79.0mm long
Weight	11.0 lbs.	5.0 kg
Material	Stainless Steel	Same
Carrying Case	37.25" x 4.25" x 4.0"	946 x 108 x 102 mm

Printed in USA (7-82)

SINCO **Slope Indicator Company**
3668 Albion Place No., P.O. Box C-30316, Seattle, Washington 98103 U.S.A.
TWX: 910-444-2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073

APPENDIX 6

6-1 Equipment Information

1. Micro-Fix
2. The Model 540 DDMU
3. Atlas Deso 20
4. Atlas Heco 10
5. 635-11 Wave and Tide Recorder
6. Digiquartz pressure Transducers

6-2 Support Documentation

1. Applications and Advantages of Microprocessors in Underwater Acoustic Positioning equipment N.C. Kelland et al

2. Acoustic Positioning During Pipelaying of the Brae Forties Pipeline F.B. Rees

3. High Frequency Trials - Long Baseline Configuration

4. Application of the Micronav Acoustic Telemetering Instrumentation System During the Installation, Levelling, Piling and Dimensional Checking of the Hutton TLP Templates N.C. Kelland et al

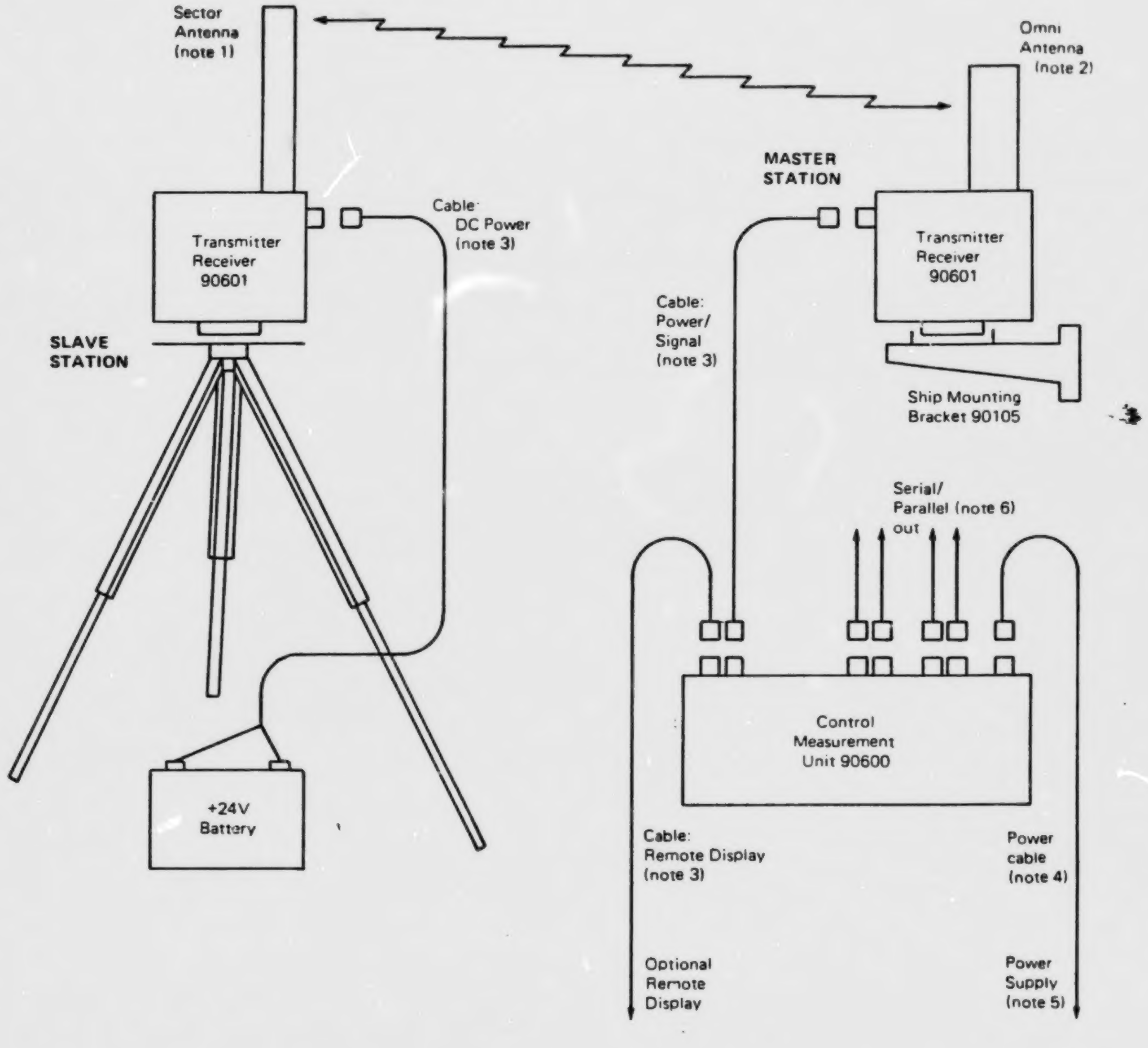
APPENDIX 6-1

EQUIPMENT INFORMATION

MICRO-FIX

General Description

- Low power solid state transmitter allows immediate ranging with automatic self-calibration.
- Circular polarisation ensures null-free operation and rejection of reflection using a single antenna.
- Accuracy maintained over the operating temperature range by continuous self-calibration.
- Master and Slave T/R units interchangeable.
- Data transfer in both directions allows automatic monitoring of deployed Slave stations and transfer of other information.
- Standard facilities include track guidance, plotter drive and real-time clock.
- Both units designed for low power consumption


Sector
Antenna
(note 1)
Omni
Antenna
(note 2)
MASTER
STATION
Transmitter
Receiver
90601
Cable:
DC Power
(note 3)
Transmitter
Receiver
90601
SLAVE
STATION
Cable:
Power/
Signal
(note 3)
Ship Mounting
Bracket 90105
Serial/
Parallel (note 6)
out
Control
Measurement
Unit 90600
+24V
Battery
Cable:
Remote Display
(note 3)
Power
cable
(note 4)
Optional
Remote
Display
Power
Supply
(note 5)

Notes:

1. Sector antenna to be specified as follows:

   Sector antenna (90° x 6°) 90612/1/3/1
   Sector antenna (90° x 30°) 90613/1/3/1

2. Omni-directional antenna to be specified as follows:

   Omni-directional antenna (360° x 20°) 90610/1/3/1
   Omni-directional antenna (360° x 30°) 90611/1/3/1

3. Cables are available in set lengths to suit installation requirements. Refer to Technical Data Summary for part numbers and lengths.

4. Power cable determined by power supply available. Set lengths are available with unterminated ends. Refer to Technical Data Summary for part numbers and lengths.

5. Power supply either 110v/230v 50-400Hz or +18v to 36v d.c. CMU must be fitted with the appropriate power supply unit. AC line voltage is selectable on the AC Power Supply Unit 90515/1/3/6.

6. Two comms. boards can be fitted. Each board has the option of serial and/or parallel output.

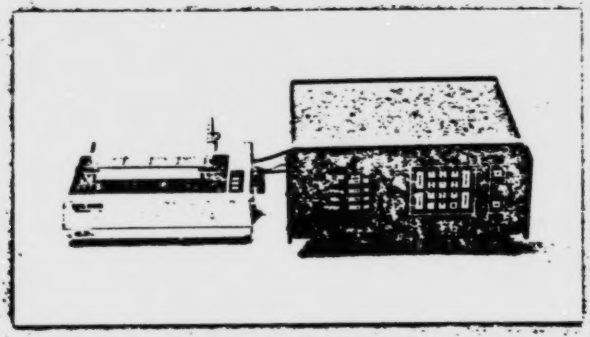
The MODEL 540 DDMU

The Model 540 is the most advanced DDMU available. It is microprocessor-based and controllable to give you exceptional reliability and flexibility. The unit allows you to select any four of more than 80 different remote codes and view them in any order you decide.

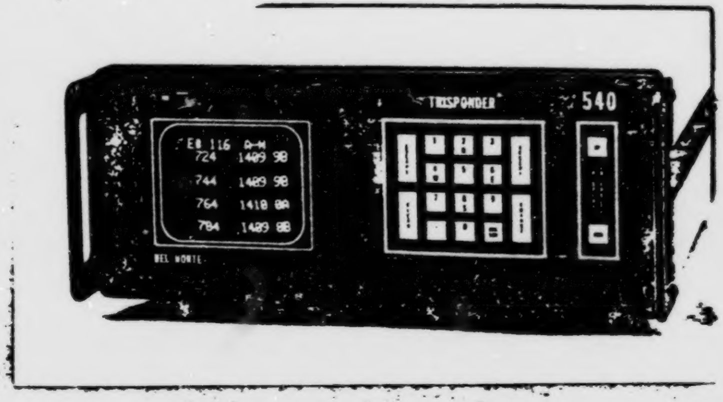
Data is deskewed to the same point in time, overcoming time lags—boat movements—between and during range sequences. The unit provides typical accuracy of ± 1 meter and gives you 0.1 meter resolution as well.

Designed to work with present TRISPONDER Master/Remote units, the 540 DDMU contains an automatic tracking gate that greatly reduces multi-path and undesirable signals. Unlike many other units, the 540 is very simple to operate.

The multi-user function allows eight users for each remote for each update interval. Update interval time also is adjustable from one-fourth of a second to five seconds. A digital calibration factor for each remote is stored in the non-volatile memory so that new remote stations can be added "on the fly".



The standard serial ASCII (RS-232C) data output allows commercially available accessories such as computers, data loggers, printers, plotters, magnetic tape recorders, etc., to be used. Parallel BCD is available as an option. It also accommodates increased operational demands when position information redundancy is required.



Internal batteries maintain all operating parameters in memory for more than thirty days, protecting you against loss of memory in case of power failure or inadvertent system shutdown. You can select from the front panel key pad a high or low baud rate. Baud rates available are 300, 600, 1200, 2400 or 4800.

See the specifications chart on the back page of this brochure for a listing and description of the Model 540's equipment options.

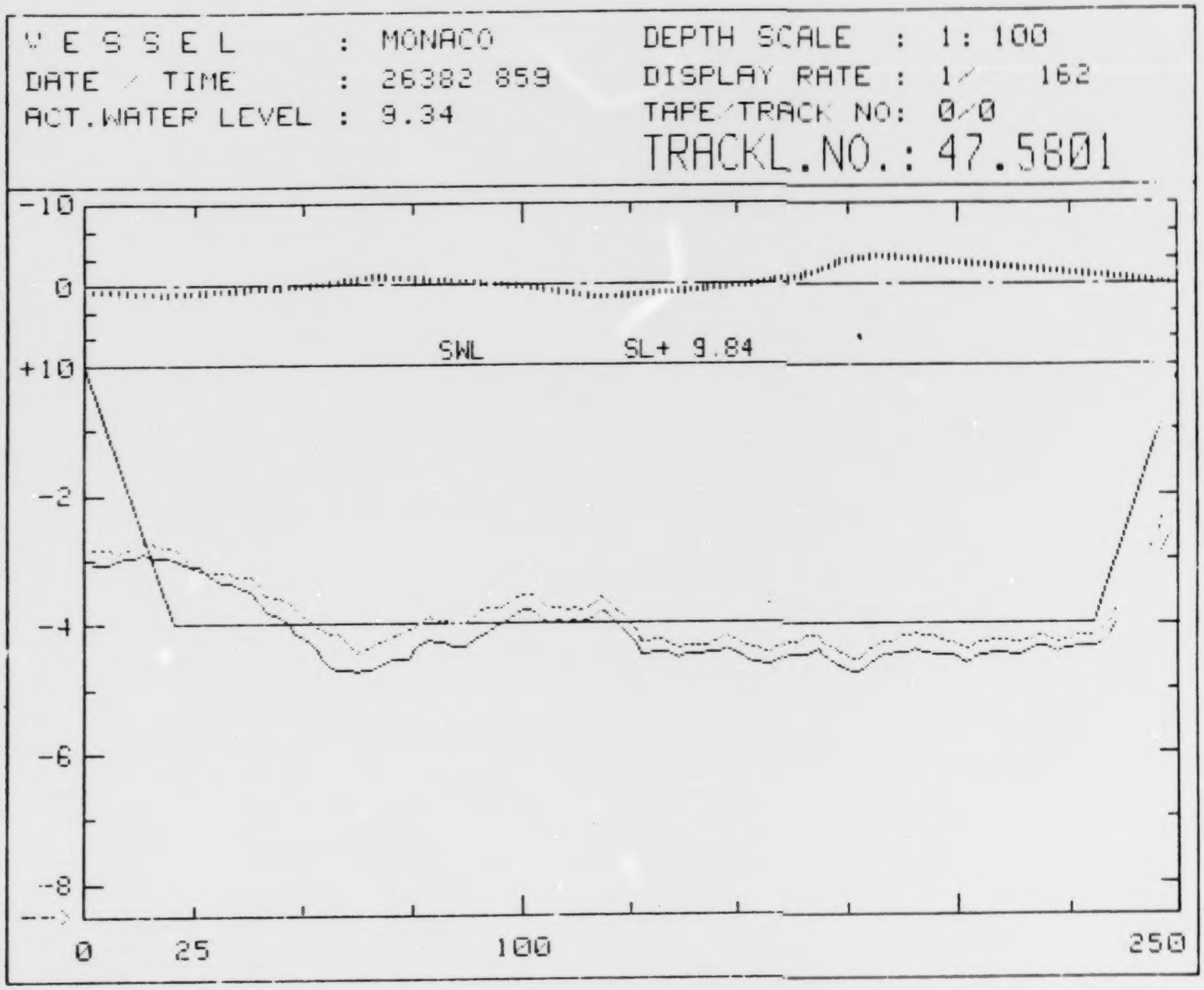
Guidance

DEL NORTE's guidance software package is a standard feature in the Model 540 DDMU to provide the user automatic and accurate guidance over a specified working area. When guidance is not required, the Model 540 reverts to standard ranging function.

Features:

- Left/right steering indicator
- Distance to go
- Line spacing
- Present line number and direction
- Ground speed indicator
- X-Y position
- Line closure rate
- Automatic scale change
- Automatic scale indicator
- Line number step direction indicator
- Controllable anti-null included in software
- Operator choice of range or X-Y position output
- Video output for remote monitor

play, the on-line quality check can also be made at the computer display (Fig. 7). Thus it provides continuously updated information on a vessel's position as it moves along a particular survey line. Any abnormal position or depth reading is distinctly visible on the screen. Moreover, should information be disrupted by, for example, the propeller wash of passing vessels, the operator now has correct information on which to decide whether the survey line must be repeated.



VESSEL : MONACO
DATE / TIME : 26382 859
ACT.WATER LEVEL : 9.34
DEPTH SCALE : 1: 100
DISPLAY RATE : 1/ 162
TAPE/TRACK NO: 0/0
TRACKL.NO.: 47.5801

Fig. 7: ATLAS SUSY 30 ONLINE GRAPHICS:
Cross Section and Vessel Track

Atlas Deso 20

The Compact, High Performance Dual-Frequency Survey Sounder

The ATLAS DESO 20 survey sounder is designed for wide applications in

- Inland waterways and harbours
- Dredging and sediment surveying
- Coastal and offshore waters
- Hydrography and research

Performance Based on Know-How

ATLAS DESO 20 is a compact dual-frequency survey sounder for shallow and deep water applications which provides not only accurate data of the water depth but also reliable information of the bottom structure, such as sediments, layers, wrecks etc.

Its excellent performance is based on KAE's extensive expertise in the design and production of precision survey echo-sounders, which are today operated on

- Survey launches and seagoing ships
- Dredgers
- Oceanographic research vessels
- Naval vessels
- Special vessels for the offshore industry

Flexible and Universal

ATLAS DESO 20 can be deployed as a portable survey sounder on very small ships and also as a fully integrated component of major systems onboard large vessels.

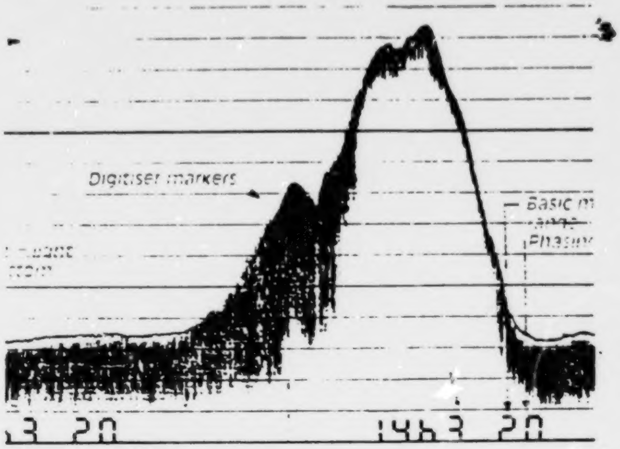
Built-in functions like dual-channel digitizer, remote paper feed control, paper distortion correction, and echo-contrast amplifier can be combined with a wide range of peripherals and options.

The heave compensator ATLAS HECO 10, the stabilized offshore transducer, a water sound velocity calibration transducer, a record annotator and remote displays are accessories which put the ATLAS DESO 20 into a class of its own as a complete survey echosounder system.

Comprehensive information

The crisp and clear echogram recording is annotated with all important parameters, such as

- Digitiser tick marks
- Water sound velocity
- Basic measuring range and phasing
- Depth threshold line
- Time, distance, and event markers



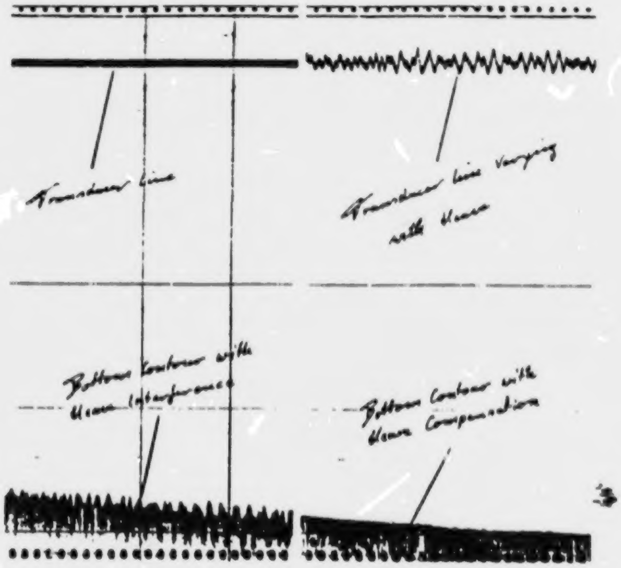
Atlas Deso 20

- High precision universal survey capabilities
- State-of-the-art technology in the mechanical design and in analogue and digital signal processing
- Simple installation and operation
- Modular design for ease of maintenance
- Simple integration into computer-controlled survey systems
- High quality and reliability of operation even under severe conditions
- Ultimate flexibility through built-in growth potential and simple interfacing of options such as heave compensator, offshore package, remote displays, record annotator, and a variety of different transducers for almost any application.

ATLAS DESO 20 is the compact and rugged survey sounder in use with most hydrographic survey organisations all over the world.

Atlas Heco 10

The Heave Compensator for Survey Sounder Atlas Deso 20



ATLAS HECO 10 is a gyro-stabilized heave compensator for on-line compensation of ATLAS DESO 20 depth measuring errors caused by heave and swell at sea.

More survey days at sea

Hydrographic survey operations in coastal and offshore waters are often disrupted by unfavourable weather conditions. The application of the ATLAS HECO 10 increases the number of effective survey days by reducing the heave-induced depth errors resulting from sea-state. Thus the efficiency of hydrographic surveys is increased and will provide users with significant cost savings. Specified survey accuracies are kept within acceptable limits even when weather conditions are unfavourable.

The optimal technical concept

The vertical motion of the survey ship is determined and compensated by applying an inertial method. An accelerometer with its sensitive axis vertically stabilized by a horizontal gyro measures the vertical accelerations resulting from heave. The acceleration signal is fed into an analogue amplifier which, in the range of heave periods from 1 s to 20 s, shows the behaviour of a double integrator. Thus, by double integration of the heave acceleration, the heave signal is generated.

An analogue signal with a sensitivity of 4 V/m is available at the output of the amplifier unit. Optionally, the heave sensor can be equipped with angular transmitters (synchros) for determining the ship's roll and pitch motions. Thus, a high-accuracy horizon reference can be made available simultaneously.

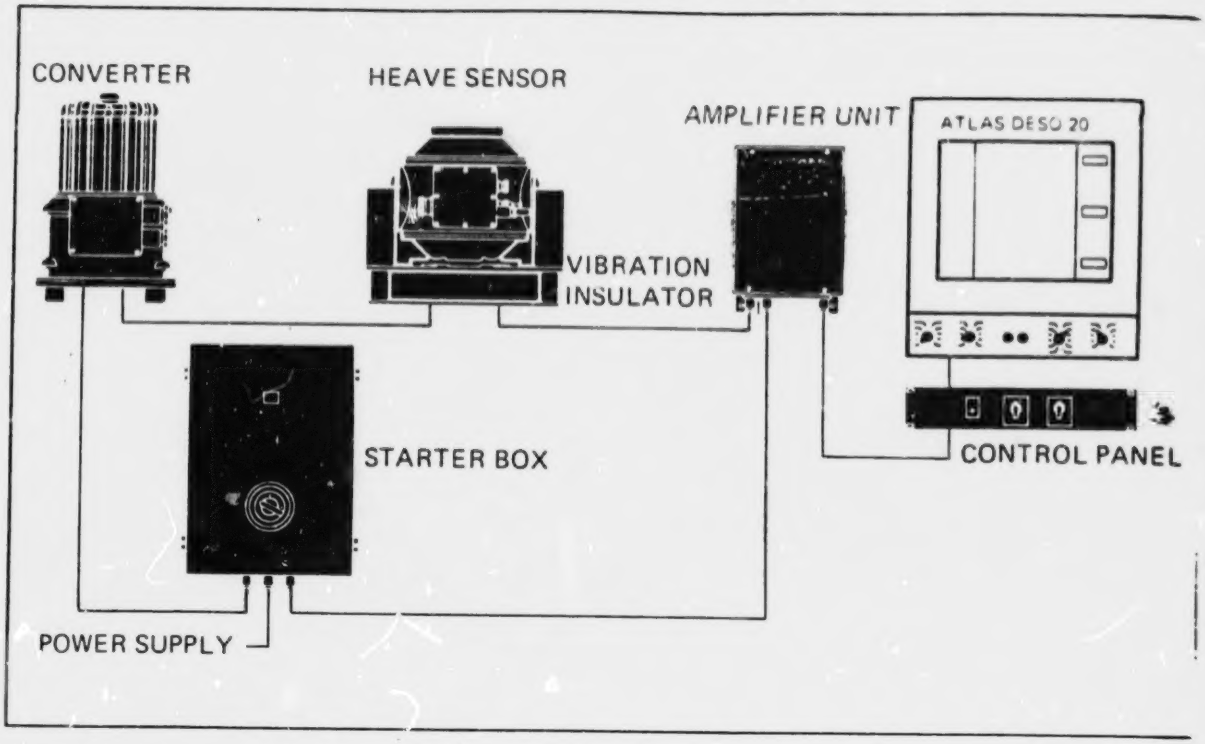
ATLAS HECO 10 heave sensors are installed on many governmental and private survey vessels all over the world, enhancing the performance of ATLAS DESO 10 or −20 echosounders for efficient survey operations.

Atlas Heco 10

- Increases effective survey time under swell conditions in coastal and offshore waters
- Provides accurate depth soundings under unfavourable weather conditions
- On-line heave compensation
- General purpose analogue heave output
- Simple and unattended operation
- Rugged design
- High reliability

Atlas Heco 10

Specification and Performance Data


CONVERTER
HEAVE SENSOR
AMPLIFIER UNIT
ATLAS DESO 20
VIBRATION INSULATOR
STARTER BOX
CONTROL PANEL
POWER SUPPLY

Measuring range: ± 2.5 m (± 5 m on request)

Measuring error: ± 5 cm ± 5 per cent of the measured value on straight courses

Output signal: 4 V/m (2 V/m)

Power supply:

Voltage	– 220 V/50 Hz or 115/60 Hz single phase; other voltages on request
Power	– 600 VA approx. Starting current 16 A max.

Option:
Roll and pitch compensation with synchro transmitter output.

Number	1 per axis
Ratio	360°/rev.
Power supply	115 V/400 Hz/3-phase

Dimensions and weights:

	Width	Depth	Height	Weight
Starter box	475 mm	342 mm	157 mm	14.0 kg
Converter	250 mm	250 mm	421 mm	24.0 kg
Heave sensor	413 mm	388 mm	400 mm	24.0 kg
Amplifier unit	308 mm	190 mm	233 mm	3.2 kg
Control panel	475 mm	90 mm	89 mm	2.1 kg

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635-11

WAVE AND TIDE RECORDER

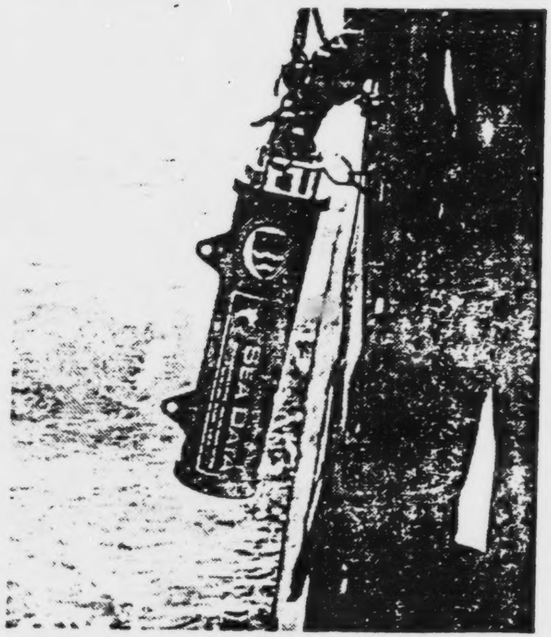

Photo courtesy U.S. Army Corps of Engineers

FEATURES:

- Uses the Paroscientific Quartz Sensor
- Simultaneously Records Wave and Tide Data
- Time Series Recorded for each Wave Burst, Allowing Several Data Analysis Techniques
- 0.05 cm Depth Resolution (20 m Range), 0.002°C Temperature Resolution
- Uses the Sea Data Model 610 Recorder with 15-Megabit Data Capacity
- Fully Reparable (Unpotted) Electronics
- Never Needs Calibration
- Rugged Electronics Rack and Pressure Case
- Unmonitored Deployments up to 16 Months in Duration Possible

THE 635-11 WAVE AND TIDE RECORDER

The 635-11 is a self-contained digital-recording wave and tide gauge intended for subsurface deployment. It is a breakthrough instrument that continues the tradition of superior performance established by its Sea Data forerunners. Small in size and convenient to use, the Sea Data pressure gauges employ super-stable quartz pressure sensors, with unique electronic circuits to achieve unsurpassed accuracy and resolution. The 635-11 measures waves by recording water height or pressure with a resolution of one part in sixty-five thousand, and retains the "absolute depth" property that is necessary for storm surge measurements. The 635-11 also measures tides with a 20-bit integration over a time interval from 30 seconds to 15 minutes. With over 100 units in the field today, this instrument has proven itself effective and reliable. The 635-11 is a versatile and powerful digital wave and tide recorder, and has become an accepted industry standard.

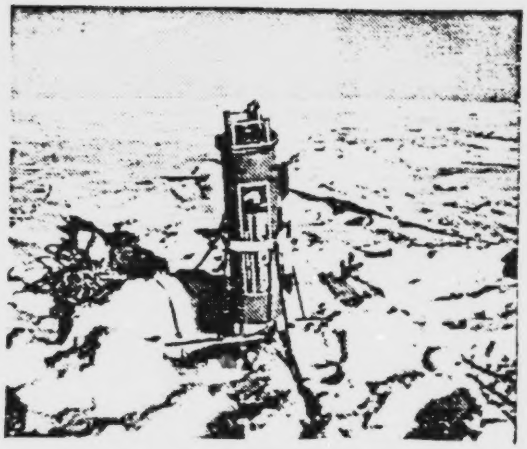

Photo courtesy Oceanographic Services Inc

APPLICATIONS:

- Tide, Wave and Storm Surge Measurements
- Seiche Studies
- Water Resource Management
- Land-Sea Boundary Determinations
- Sea-Surface Tilt (and thus Current Flow)
- Sub-Ice Deployments
- Offshore Platform Site Surveys
- Working Conditions Surveys
- Wave Climatology, Hindcasting

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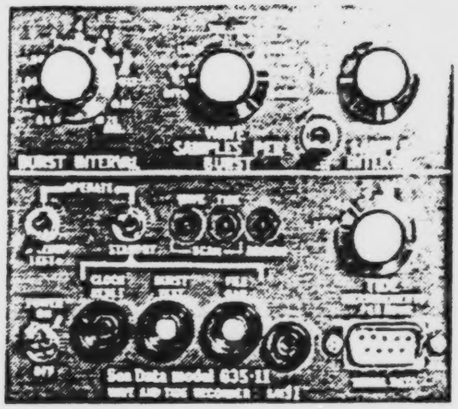
A CLOSER LOOK

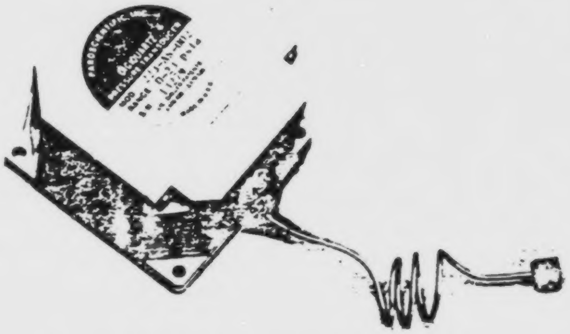


THE FRONT PANEL:

The five wave and tide programming switches on the 635-11's front panel offer you a wide choice of measurement patterns so that you can optimize data acquisition to suit your experimental needs. Time between wave bursts is switch-selectable from 0.5 to 24 hours in 11 steps. The number of samples per wave burst is selectable from 64 to 2048 in six steps, with additional settings disabling wave recording entirely or programming for continuous wave measurements. Time between individual measurements is switch-selectable from 0.5 to 16 sec. in six steps. The BURST TEST, STANDBY AND SPEEDUP switches allow you to test the 635-11 before deployment. The clocks, sensor electronics and sensors can be checked using a Sea Data Model 18 VDM connected to the serial data port on the 635-11's front panel. In short, the front panel of the 635-11 gives you tremendous programming power and access to the instrument's electronics.

THE PAROSCIENTIFIC QUARTZ SENSOR:

An idea of the unusual quality of the Paros sensor can be seen from its .005% maximum worst-case hysteresis error, over a full range pressure excursion. Corrected measurements approaching 5 ppm can be obtained with the Paroscientific sensor. This remarkable performance is achieved through the use of a special quartz crystal resonator whose frequency of oscillation varies with pressure-induced stress. The result is much better than other quartz sensors which measure the stress by sensing capacitance. In the 635-11, this sensor provides a wide dynamic range and good linearity to allow the measurement of small waves at greater than usual water depths. And it provides nearly ideal absolute pressure data for the tide measurements.



PAROSCIENTIFIC "DIGI-QUARTZ" SENSOR SPECS

	100 psia		45 psia	
	feet	meters	feet	meters
Standard Ranges:	190	60	65	20
Abs. Maximum Depth:	235	70	90	25
Resolution - waves:	0.0035	0.1 cm	0.0015	0.045 cm
tides:	0.004	0.12 cm	0.0017	0.05 cm
Accuracy-				
less than 80 ft:	0.03		0.014	0.4 cm
more than 80 ft:	0.05 ft		(these aren't typos!)	
vs temp @30 ft	0.004 ft/°C (max)		0.003 ft/°C (max)	

Other ranges available: 10 and 120 meters. The 100 psi sensor is the preferred sensor, due to the limited overanging (120% of full scale) of these sensors. The resolution will meet your needs and the instrument can be used in more locations.

SEA DATA
OCEANOGRAPHIC INSTRUMENTATION
NEWTON, MASS. U.S.A.

THE PRESSURE CASE:

The standard pressure case for the 635-11 is constructed of 6061-T6 aluminum with a welded bottom endcap. All surfaces of the case and top endcap are given a corrosion resistant Sanford hardcoat and all external surfaces also receive a electrostatically-applied fused epoxy coating for further abrasion and corrosion resistance. All cases and endcaps, including connectors, are pressure tested to 2000 psi. Zinc anodes provide corrosion protection. A PVC base allows setting the 635-11 on a rough deck.

MODELS:

635-11	(world standard wave and tide recorder)
635-11A	(additional sensor for atmospheric data)
635-11R	(remote sensor-- up to 1000 meters)
1235-11	(environmentally secure fiberglass case)
1735-11, 1735-11A	(standard relay rack mount)

The 635 series is mounted in a 6" pressure housing, while the 1235 is in a 12" fiberglass case and the 1735 uses a 17" relay chassis.

OTHER SENSORS:

In addition to the remote and surface pressure sensors mentioned previously, you can order your 635-11 with additional temperature sensors, a conductivity sensor, or the new Wotan surface wind speed accoustic sensor. The 635-11 has three spare card slots.

1.4 DETAILED SPECIFICATIONS of the 635-11.

PRESSURE - water height
Sensor: PAROS SCIENTIFIC "DIGI-QUARTZ"
Standard Ranges: 170 ft (55 m) 60 ft (20 m)
Resolution - waves: 0.003 ft 0.0015 ft
tides: 0.003 ft 0.0015 ft
Accuracy: 0.01 ft 0.005 ft (these aren't typos!)
FM Noise: below limit of resolution.
Stability: 0.0002% at (almost constant) ocean depths.
Ranges Available: 10, 20, 55, 120, 190, 250, and 600 meters.

TEMPERATURE
Range: 0.0°C to 25.5°C (approximately linear)
Resolution: 0.002°C (degrees centigrade)
Accuracy: 0.07 °C (Special versions to 0.01°C)
Stability: 0.005°C (small temp. excursions)
0.02 °C (full temperature cycling)
FM noise: 0.002°C

TIDE PROGRAMMING
Duration: 28.125 seconds to 15 minutes, with Koehler memory integrators.
Rate: 128 - 64 - 32 - 16 - 8 - 4 measurements per hour.

WAVE PROGRAMMING - from 0.5 hour to 24 hours between bursts as follows:
Interval: 0.5 - 1 - 1.5 - 2 - 3 - 4 - 6 - 8 - 12 - 16 - 24 hours.
Burst rate - seconds: 0.5 - 1 - 2 - 4 - 8 - 16 seconds per sample.
- hours: 8192 - 4096 - 2048 - 1024 - 512 - 256 measurements per hour.
Burst Duration: 64 - 128 - 256 - 512 - 1024 - 2048 samples per burst, and "CONT" continuous burst... for example 17 days at a 2 sec rate.

TIMEBASE: 4.194304 MHz special quartz crystal.
Stability: 0.1 ppm/°C, 1 ppm/year.
0.0001% pressure error at ocean depths.

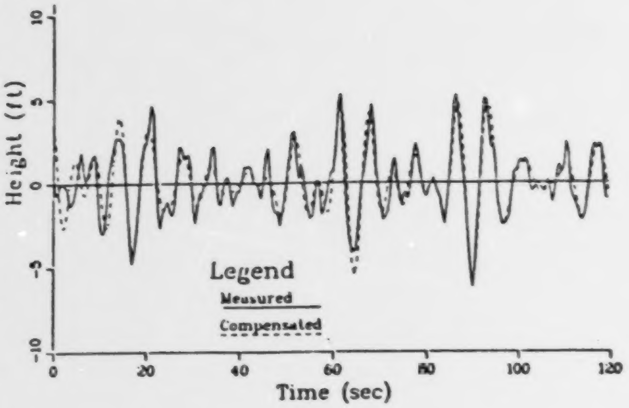
RECORD FORMAT - 2 simultaneous interleaving formats:
Tides: mode, header, time, 8 sets of pressure and temperature, parity.
Waves: mode, burst record number, 16 pressure samples, parity.

DATA FORMAT
Time: 20 bits binary, up to 14 months before "wraparound".
Pressure: tides, 20 bits binary; waves, 16 bits binary.
Temperature: 16 bits binary.

DATA STORAGE
Media: Standard digital certified 300 and 450 ft. cassette tapes.
Format: 800 bpi bi-phase code on 4 tracks: 10 megabits (300' tape).
Capacity: 48,000 data records, 308 data bits each.

POWER SDB-4 Sea Data 20 AHr Alkaline battery - good for 6 months.
SDB-4L Sea Data 40 AHr Lithium battery - good for 1.5 years.
SIZE - case: 7" diam. x 23" long.
- mounts: two 0.5" bolt holes on 13" centers, 1.0" clearance.
WEIGHT approx 40 lbs. in air, with battery, xx lbs in water.

PRESSURE CASE
Material: 6061-T6 Aluminum
Hardware: 316 Stainless and Delrin insulators
Finish: Hard-coat anodize with polyurathane paint overcoat
Depth: 1100 meter operating depth.



DATA PROCESSING:

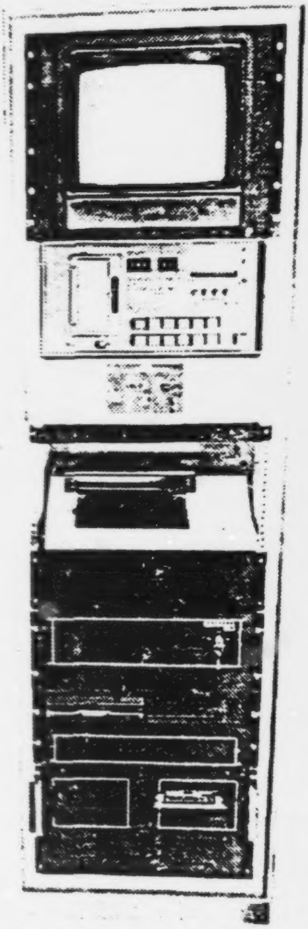
For processing your 635-11 data, we have assembled a package of instruments and software that will take care of all your data processing needs. Pictured on the right is our wave analysis system, featuring a Sea Data Model 12B Reader and ARI, a Ball high-resolution graphics screen, a Hewlett Packard 7225 plotter, and an Intersystems 800 computer with 0.5 Mbyte of Ram, triple 8" floppy disk drives and a 40 Mbyte Winchester hard disk drive. All of the above hardware is housed in an Optima equipment rack. This system handles the complexity of Fourier time series analyses and energy density calculations both quickly and efficiently. In minutes, you can convert from raw pressure data to a complete breakdown of the components of the energy spectrum at your deployment site, or a compensated reconstruction of the surface displacement time series. The system also includes a Televideo terminal and a printer (not pictured). All software needed for data processing is included in the package.

OTHER PRESSURE GAUGES:

Several other models of pressure gauges from Sea Data are designed for wave and turbulence recording. The 635-8 gauge features burst-mode recording for wave measurements, and like the -11, uses the Paros quartz sensor with special electronic amplifying circuits to achieve 1:65,000 resolution with 1 second measurements. The 635-9 gauge adds an electro-magnetic (EM) current sensor to the wave circuits of the 635-8 to allow wave direction determination. The 635-12 also has an EM current sensor and uses special data compacting schemes to achieve multisensor data: mean current, tides, temperature, wave heights, and wave direction. It is particularly suited to wide-spectrum general site analysis. Another alternative for tide measurements is the TDR, a low-cost digital thermograph-depth recorder which is capable of recording 20,000 measurements.

SUBSURFACE MEASURING TECHNIQUES.

Because the Sea Data 635-11 Wave and Tide recorder measures pressure from some depth below the surface, it does not directly measure wave height, but instead measures a short-period attenuated version of wave heights. The Paros sensor used in the 635-11 has suffficent resolution to allow you to compensate for the effects of depth attenuation with the proper data processing techniques. The graph on the left, taken from "Subsurface Wave Measuring Systems" by George Z. Forristall of Shell Development Company shows the correspondence between wavestaff measurements and compensated measurements from a Paros Sensor mounted 56 feet below mean sea level on the Buccaneer test platform in the Gulf of Mexico.

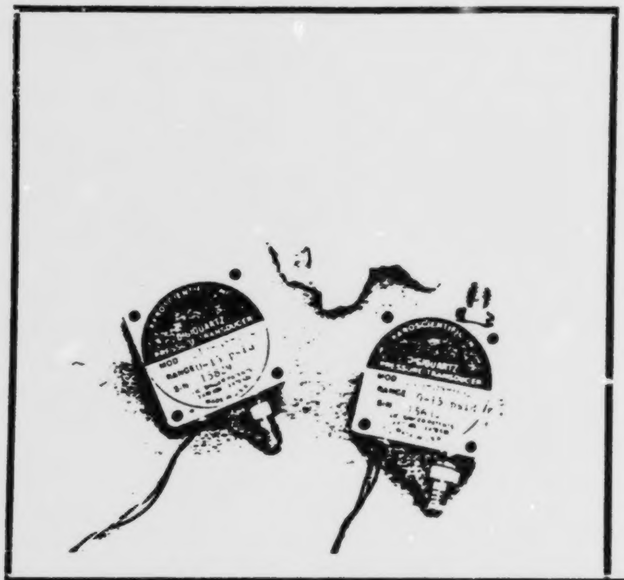


For more information about the Sea Data 635-11 Wave and Tide Recorder, or about other Sea Data Products, please get in touch with us!

PAROSCIENTIFIC .INC.
precision pressure instrumentation

4500 - 148TH AVENUE N.E.
REDMOND, WA 98052 U.S.A.
TELEPHONE (206) 883-8700
TELEX 152901 (PARO RDMD)

DIGIQUARTZ® PRESSURE TRANSDUCERS



FEATURES

- DIGITAL-TYPE OUTPUT
- LOW POWER CONSUMPTION
- SMALL SIZE AND WEIGHT
- PRESSURE STANDARD ACCURACY
- HIGHLY STABLE AND RELIABLE
- INSENSITIVE TO ENVIRONMENTAL FACTORS

APPLICATION AREAS

- METEOROLOGY
- OCEANOGRAPHY
- AIR DATA SYSTEMS
- JET ENGINE TESTING
- PROPULSION CONTROL SYSTEMS
- WINDTUNNEL INSTRUMENTATION
- TRANSFER PRESSURE STANDARDS
- ENERGY EXPLORATION AND WELL TESTING

The DIGIQUARTZ® PRESSURE TRANSDUCERS represent a significant advance in the pressure instrumentation field. Overall precision is better than 0.01% maintained under difficult environmental conditions. Other characteristics include high stability, reliability, low power consumption, and a small, self-contained package. The output signal interfaces easily with counter-timers, telemetry, and digital computer systems.

The remarkable performance is achieved through the use of a special quartz crystal resonator whose frequency of oscillation varies with pressure induced stress. Quartz crystals are used in almost every frequency standard application because of their excellent stability, superior elastic properties, and insensitivity to effects such as temperature.

When installed in the Model 300 Shock Mount, the transducers are capable of withstanding extremely high acceleration, shock, and vibrational loads. These transducers are the key sensing elements in a series of highly sensitive and accurate submersible water level gauges called the DIGIQUARTZ® DEPTH SENSORS.

Additional descriptive information is available in our technical brochures and application notes.

DESIGNATION*	RANGE
Model 215-DS-002	0 to 15 psid (0.10 MPa)
Model 230-DS-002	0 to 30 psid (0.21 MPa)
Model 215-AS-002	0 to 15 psia (0.10 MPa)
Model 223-AS-002	0 to 23 psia (0.16 MPa)
Model 230-AS-002	0 to 30 psia (0.21 MPa)
Model 245-AS-002	0 to 45 psia (0.31 MPa)
Model 2100-AS-002	0 to 100 psia (0.69 MPa)
Model 2200-AS-002	0 to 200 psia (1.38 MPa)
Model 2300-AS-002	0 to 300 psia (2.07 MPa)
Model 2400-AS-002	0 to 400 psia (2.76 MPa)
Model 2900-AS-002	0 to 900 psia (6.21 MPa)

SPECIFICATIONS (% of Full Scale Except as Noted)

Repeatability	0.005%
Hysteresis	0.005%
Temperature Null Shift	0.0004%/°F (0.0007%/°C)
Temperature Span Shift (% of Reading)	0.0026%/°F (0.0047%/°C)
Acceleration Sensitivity	0.002%/G
Vibration Sensitivity	Negligible
Excitation Voltage Sensitivity	Negligible

CHARACTERISTICS

Nominal Frequency Excursion (Zero to Full Scale) (Most Models)	40 kHz to 36 kHz
Operational Temperature Range	-65°F to 225°F (-54°C to 107°C)
Operational Vibration Spectrum	MIL-E-5400-III
Power Requirements	6 to 35 Vdc. 0.001A.
Size	0.89 x 1.56 x 1.56 in. (2.26 x 3.97 x 3.97 cm)
Weight	6 ounces (0.17 Kg)
Overpressure	1.2 x Full Scale

Registered Trademark of PAROSCIENTIFIC, Inc.

Specifications subject to change without notice.

Manufactured under one or more of the following U.S. Patents
3,470,400 - 3,479,536 - 4,215,570 - 4,321,500 Other patents pending

Figure 3 shows the strain contours for borehole D2, and the results are summarized below:

(1) Due to this hole being beyond the influence of the rear pillar the general pattern of the strain contours are completely different than those for borehole D1.

(2) There is a change from compression to tension just behind the face line, after which the spacing of the tensile strain contours increases. This shows that the beds are cantilevering about the solid coal, and then deflecting down into the excavation. The increase in spacing of the contours indicates that the curvature of the strata decreases as it comes into contact with the waste.

K6 Instrumentation

Above the second longwall face, K6, three vertical boreholes were instrumented with a Soil Instruments inclinometer, to monitor lateral movements in two orthogonal directions. Vertical movements were measured from magnetic anchors, attached to the outside of the inclinometer guide tubes, sensed by a reed switch probe. The positions of these boreholes were: above the centre line (D3), half way between the ribside and the face centre line (D4), and 10 metres beyond the ribside over the solid (D5).

Unfortunately due to high concentration of methane flowing out of the boreholes, they had to be sealed off just behind the faceline. This meant that no significant vertical movements were measured, hence only the lateral deformations are presented.

Lateral Deformations Above K6

In order to interpret the measured lateral movements is was necessary to assume that the bottom of the inclinometer tubes have remained stable. Judging from the asymptotic nature of the curves for boreholes D3 and D4, Figures 5 to 8, this assumption is correct.

Due to floor heave just in front of the face causing excessive distortion of these two holes no movements were measured behind the face line. Since the third inclinometer hole, D5, was located over the solid there was not enough movement to damage the lining, however, no significant lateral deformation was measured in this hole, as the face went past, and finished 15 metres (49 ft) away.

Movements parallel to the direction of face advance. The lateral movements measured in both holes parallel to the direction of face advance, Figures 5 and 6, show that the strata movement towards the face increases, as the height above the seam increases. This type of movement is what would be expected from the drawing effect of the subsidence trough, ie subsidence movement occurs first at higher levels.

For borehole D3, Figure 5, at 16 metres (53 ft) in front of the face only the top 32 metres (106 ft) of the hole has moved laterally. This probably indicates where the 'line of draw' intersects the borehole, giving an angle of draw 70° from the horizontal. As the face advances to within 10 metres (33 ft) of D3 the lateral displacement over the length of the hole decreases by over 50%. This was probably due to the bottom of the hole moving towards the face, since at this face position using an angle of draw of 70°, all the borehole is within the zone of draw. Movement trajectories above a longwall face, Figure 4a, as calculated by the National Coal Board, clearly indicate this.

In borehole D4, Figure 6, there was no evidence of the borehole straightening. This is due to the lateral movements being smaller and starting later in this hole, owing to its proximity to the ribside.

Movements parallel to the face line. The movements parallel to the face line for borehole D3 are shown in Figure 7. The maximum horizontal movement of 15 mm (0.6 inches) in this direction is approximately 20% of that measured perpendicular to the face. In fact no movement was expected in this direction, as in theory movements should be symmetrical about the centre of the excavation. This can be clearly seen from Figure 4b showing the movement trajections parallel to the face line.

For borehole D4 the movements parallel to the face are shown in Figure 8. This borehole demonstrates a slight tilt towards the ribside when the hole is 10 metres (33 ft) ahead of the face. As the face advances to within 3 metres (10 ft), the bottom half of the hole bends further towards the ribside, whilst the top of the hole bends towards the centre-line. It can be seen that the displacement profile is no longer asymptotic towards the vertical, possibly implying that the bottom of the hole has moved.

Conclusions from lateral deformations. The lateral movements can be compared with measurements of permeability taken by Neate (1979) above K6 face. The results he obtained concerning the position of the onset of change in permeability, and peak permeability are shown in Figure 9. It can be seen that the peak permeabilities are occuring before any lateral movement was recorded. Somewhat surprisingly this seems to indicate that there is very little correlation between permeability and lateral movement.

A summary of the conclusions that can be drawn from these measurements of lateral movement are:

(1) There was no correlation between lateral movement and geology.

(2) The general trend of movements is towards the centre of the excavation.

(3) Ahead of the face the error in the measurement of vertical deformations due to lateral movement is negligible.

(4) There is no apparent correlation between horizontal movement and changes in permeability.

CASE STUDIES

In order to obtain sufficient measurements of vertical strain, over a range of different conditions, it has been necessary to consider case histories of inter-strata movement from the literature. Full details of four other investigations have been obtained, two in Britain, and two in the United States. All measurements have been taken using the strainwire/anchor/extensometer technique, and presented as contours of vertical strain. The site details and results are discussed in the following section.

Whitburn/Wearmouth Collieries, Durham (Malone 1966)

At this site movements above the NW6 face in the Harvey seam at Whitburn Colliery were monitored from an airway 59.8 metres (196 ft) above, in the Hutton seam at Wearmouth Colliery, Figure 10. The NW6 face was a 182 metre (600 ft) wide advancing unit, with an average extracted height of 1.06 metres (3.5 ft), at a depth of 463 metres (1520 ft). Measurements of inter-strata movement were taken from two boreholes, D6 and D7. The positions of these two holes was over the face centre line, and 54 metres (175 ft) from the centre line, respectively.

Whitburn/Wearmouth results. The strain contours for boreholes D6 and D7 are shown in Figures 11 and 12. The important features are summarised below:

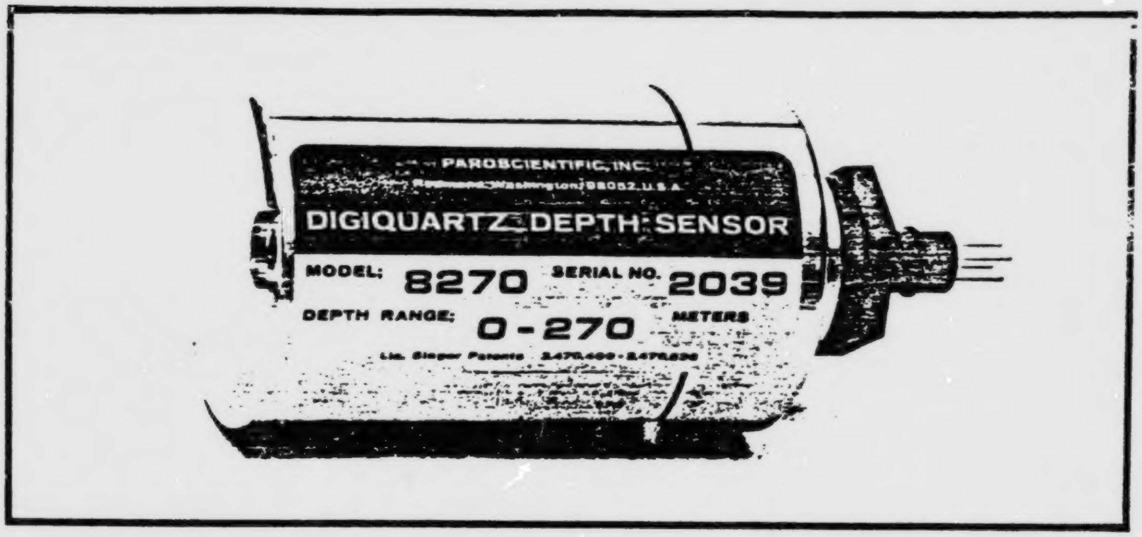
(1) There is a zone of compression in front of the face, with the strains decreasing with height above the seam. This compression zone tends to lean back over the goaf, as can clearly be seen at D6, but to a lesser extent towards the ribside at D7. This shows that the strata is cantilevering as a series of separate beams, with the leaning back over the goaf due to the higher beds resting on the span of the lower beams.

(2) There is a reduction in strain above the seam with increasing distance behind the face. This suggests that the goaf began taking load 46 metres (151 ft) behind the face, and had consolidated to almost its maximum after 122 metres (400 ft) to 153 metres (500 ft) advance.

(3) There was a residual tensile strain of between 0.25% and 0.5% in the near seam strata after movement had finished. Since this value is likely to exceed the elastic tensile strain limit of coal measure rocks, it is apparent that there is some residual fracturing and bed separation, to at least 80 metres (262 ft) above the seam. These residual strains indicate that there is a permanent redistribution of stresses onto the abutments; a common cause of interaction effects in multi-seam layouts.

Markham Colliery, North Derbyshire (Batchelor 1972)

In this investigation boreholes were drilled from an airway in the 1st Piper Seam down to L58's face, 44.7 metres (147 ft) below in the Three-Quarter Seam. L58's was 200 metres (656 ft) wide, with an extracted height of 1 metre (3 ft), and lay at a depth of 585 metres (1920 ft). The instrumentation at this site consisted of four vertical boreholes, D8 to D11, the respective positions of which were; 15 metres (49 ft) over the solid, above the rib edge, half way between the ribside and the face

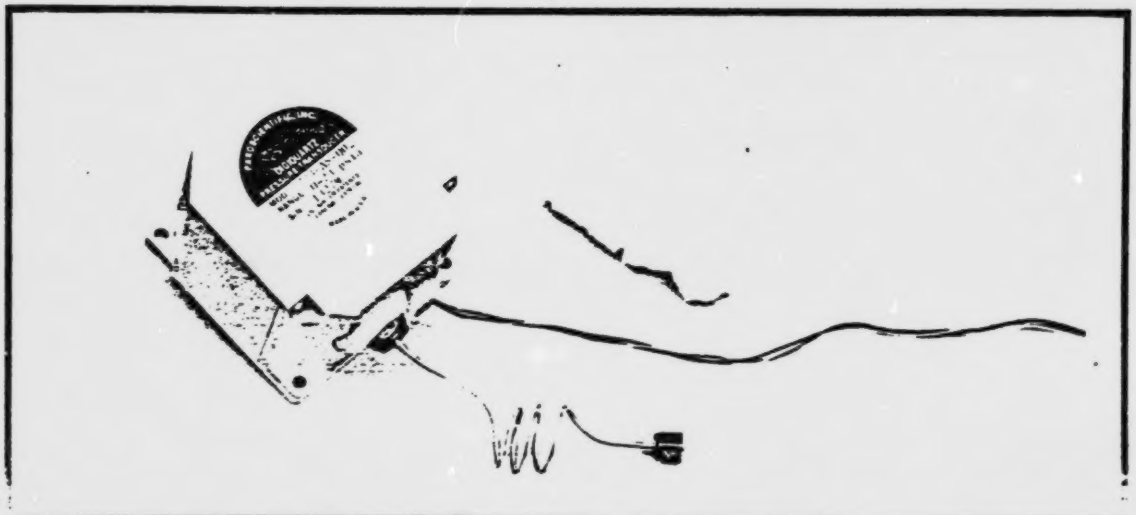


High performance water level sensors have been developed based on the existing series of quartz crystal pressure transducers. The DIGIQUARTZ® DEPTH SENSORS have a sensitivity of less than a millimeter of water at depths of hundreds of meters. These sensors are well suited for oceanographic applications because of their high accuracy, digital-type output, low power consumption, and insensitivity to environmental errors.

The sensor consists of a sealed pressure case, fabricated from 316 stainless steel, which houses a pressure transducer in a protective shock mount. The transducer is wired internally to the depth sensor's underwater connector. Pressure inputs may be transmitted either through the pressure port or by total submersion of the depth sensor. The pressure communicates with the transducer input through an internal, flexible, oil filled line.

The depth sensors may be used for real-time data acquisition or in logging systems in which hydrostatic pressure is recorded digitally on magnetic tape. Application areas include tidal and sea slope measurements, monitoring of reserv[illegible] levels, as well as tsunami, wave, and seiche studies. The low impedance output is capable [illegible] lengths of several thousand meters.

DIGIQUARTZ® DEPTH SENSOR Model:	8010	8020	8060	8130	8200	8270	8600
Depth Range (Meters of Water):	0 to 10	0 to 20	0 to 60	0 to 130	0 to 200	0 to 270	0 to 600



The Model 300 Shock Mounts are protective enclosures for the DIGIQUARTZ PRESSURE TRANSDUCERS. Extremely high acceleration, vibration, and shock loads can be sustained without damage or change in calibration. Please specify the Model 300-A Shock Mount for use with all absolute pressure transducers. Specify the Model 300-D for differential pressure transducers.

APPENDIX 6-2

SUPPORT DOCUMENTATION

Applications and Advantages of Microprocessors in Underwater Acoustic Positioning Equipment

by N.C. Kelland, M.Sc., C.J. Partridge, B.Sc. and D.C. Lawes, B.Sc. : Sonardyne Ltd.

Paper presented at HYDRO 82, the Hydrographic Society Symposium, Southampton, December 1982.

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Applications and Advantages of Microprocessors in Underwater Acoustic Positioning Equipment

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Abstract

There has been a significant increase in the application of acoustic positioning, control and data telemetry to all phases of oil field development over the past 3 to 4 years. This has placed demands on manufacturers to develop equipment of increasing flexibility and sophistication which is also robust, portable and reliable. This has been possible following the introduction of the microprocessor. This paper outlines the impact of the low power microprocessor on the design of Long-Baseline (LBL) and Short-Baseline (SBL) equipment, and ROV and Template position monitoring equipment operating in the Medium Frequency band (20-36kHz). Technical features and applications are described of a microprocessor-based transponder (Compatt) and surface acoustic transceiver (PAN), with particular emphasis on the LBL Auto-Calibration facility of the system.

Contents

1. Introduction.
2. Conventional Long-Baseline Navigation.
3. The Integrated Medium Frequency System.
4. Limitations of Conventional Long-Baseline Navigation.
5. Compatt — the "Intelligent" Transponder.
6. 'PAN' — the Universal Controller of the Medium Frequency System.
7. Compatt Auto-Calibration Trials.
8. Determination of Sound Velocity.
9. Typical Application of PAN/Compatt System.
10. R and D Implications of Microprocessor-based Equipment.
11. Recent Developments based on Microprocessors.
12. Conclusions.

1. Introduction

There has been a significant increase in the application of underwater acoustic positioning, control and monitoring to North Sea operations over the past 3 to 4 years. This has applied to all phases of oil field development from positioning pipelines and jackets, to remote control of well heads and monitoring jacket cathodic potentials. At the same time, oil companies have demanded improved measurement accuracies, better equipment reliability, longer operational life of subsea units and greater operational flexibility. Equipment has to be robust, portable, be unaffected by varying ship power supplies, and operate at any required depth in all sea states. Operational performance is also expected to be unaffected by ship noise and not to interfere with, or be affected by, acoustic systems already in use.

Until comparatively recently manufacturers of acoustic systems had to base equipment on discrete components and hard logic devices. This not only limited the flexibility of any design, but also had a significant influence on the size of units. It was thus difficult to meet the stringent demands of oil companies, and acoustic positioning equipment was in general only used on a limited basis. This situation has changed over the past 3-4 years, and the introduction of the microprocessor has given the designer the opportunity to combine greater flexibility and complexity than could be achieved with hard logic designs. The consequent decrease in the number and size of electronic hardware components has also allowed sophisticated multi-function equipment to be designed which is also robust, portable and reliable.

This paper outlines the impact of the low power microprocessor on the design of Long-Baseline and Short-Baseline equipment, and ROV and Template position monitoring equipment operating in the Medium Frequency (20-30kHz) band. Technical features and operational applications are described of a microprocessor-based transponder (Compatt) and surface acoustic transceiver (PAN), with particular emphasis on the Long-Baseline Auto-Calibration facility of the system.

2. Conventional Long-Baseline Navigation

Long-baseline (LBL) or Range-Range acoustic navigation provides accurate position fixing over a wide area by ranging from a vessel, manned submersible or Remotely Operated Vehicle (ROV) to 3 or more transponders deployed at known positions on the seabed. This type of positioning system meets the requirements of accurate local control and high repeatability demanded by the offshore construction industry, and has thus been used during the development of offshore oil and gas reserves. The first LBL system used for North Sea oil field applications was developed by Kelvin Hughes in co-operation with Sonardyne for positioning deep core drilling investigations in British Petroleum's Forties Field in the early seventies. The surface equipment transmitted signals at 30KHz to interrogate horizontally deployed seabed transponders which replied at 48KHz. The reply was received by a second transponder and displayed on a specially adapted echo sounder receiver. Different transponders were allocated different pulse-delay codes for recognition *(Ref. 1)*. There was no requirement for this analogue system to work from a vessel with way on, and position update rates were not critical.

Sonardyne also introduced their diver operated acoustic ranging equipment, the Rangemeter, in the early seventies. This equipment operated at the relatively high frequency of 60KHz and provided very high positioning accuracies (within 0.20m), but maximum ranges were generally under 500m. The equipment was used successfully by British Petroleum for accurately mapping the positions of pipelines within 150m of production platforms at West Sole *(Ref. 2)* and off Abu Dhabi.

Later, more sophisticated shipborne systems were introduced which incorporated simultaneous multi-frequency signal processing and computers for on-line position computation. These included the AMF ATNAV system *(Ref. 3)*, Polytechnics AUTRANAV and Sonardyne's Rangemaster, and all operated in the accepted 'low frequency' band 8-16KHz, with claimed positioning accuracies within 3-5m over areas up to 5 x 5km. However, this frequency band had originally been selected for long-range deep ocean work on the mid Atlantic Ridge, and in the comparatively shallow North Sea the range advantages were not realised sufficiently to compensate for the noise susceptibility and the loss of accuracy. Sonardyne thus decided to standardise on a 'Medium Frequency Band' of 20-36KHz to provide in one system good accuracy (within ±1m) and adequate range (up to 3km) for positioning requirements in underwater engineering applications. The first MF Rangemaster system was used for government research purposes in 1978, and MF version of the Rangemaster for spool piece distance measurement in Chevron's Ninian Field in 1979. Subsequently, a complete range of MF equipment was introduced for conventional LBL applications, as part of an integrated medium frequency system.

3. The Integrated Medium Frequency System *(Fig. 1)*

3.1 *Frequency Requirements within the MF Band*

The original LF band provided 17 frequencies at 500Hz intervals. Two were retained as interrogation frequencies, a common interrogation frequency of 9kHz and relay interrogation frequency of 11kHz, the remainder being available as individual transponder reply frequencies. The requirements for the MF band are more complicated:

a) The standard transponder operates in two modes
b) Frequencies are required to command the transponder
c) Frequencies are required for digital data telemetry
d) Other manufacturers use this popular frequency band, for example Simrad and Honeywell for their Super Short Baseline (SSBL) dynamic positioning system, and interference must be minimized.

3.2 *Simultaneous and Sequential Interrogation Modes*

Traditional low-frequency systems operate in the "Simultaneous" mode; one frequency is transmitted from the ship or submersible to which all transponders reply, each on their own frequency. This requires multi-channel receiving and ranging electronics, but collects data in the shortest interval, easing the navigation of moving vessels.

In "Sequential" interrogation each transponder requires a separate interrogation frequency, hence only one range is measured per interrogation cycle. With less reverberation in the water more accurate ranging is possible, but only in stationary situations. Two types of reply are possible in this mode:

a) All transponders reply on the same frequency.
b) Each transponder replies on a separate frequency.

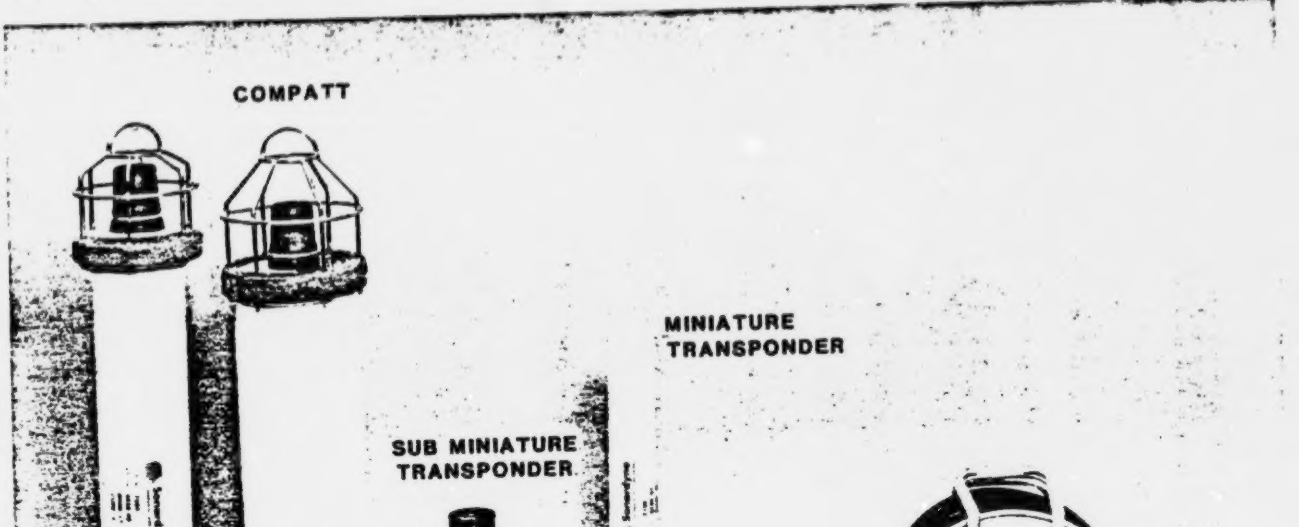

Fig. 1
Part of the Integrated Medium Frequency Family of Acoustic Equipment.

The former method is more economical in use of frequencies and simplifies the equipment since the interrogator requires only one receiving channel. The latter method requires 10 frequencies for only 5 channels, and is used by some dynamic positioning systems.

3.3 *The "Dual-Mode" Principle*

Sonardyne devized the "DMT" or Dual-Mode Transponder to combine the advantages of both interrogation modes. Two frequencies are allocated as "common" to all transponders and interrogators:

a) CIF — Common Interrogation Frequency
b) CRF — Common Reply

For each transponder channel a separate "Individual channel Frequency", or ICF is required.

Each DMT may be interrogated on either CIF or its ICF. If interrogated on CIF it will reply in Simultaneous mode on its ICF, along with all other transponders. If interrogated on its ICF it alone will reply, in the Sequential mode, on the CRF.

There are 15 standard ICFs, 8 are grouped at the low end of the band and are best suited to the longer ranges. The remainder are the "high band" channels which have better performance in terms of range resolution.

The time delay between the arrival of the leading edge of an interrogation pulse at a transponder, and the initiation of a reply pulse is known as the "Turn-around Delay". This must necessarily be at least a few milliseconds in order to identify the interrogation frequency. In the case of Sonardyne MF transponders, this delay is extended to precisely 125.7msec. This permits "down-to-zero" range measurement by allowing close-in reverberation to die away before the reply is transmitted.

3.4 *Command of Dual-Mode Transponders*

Acoustic remote-control or "Command" of transponders is useful for:

a) Enabling and disabling the transmission of replies for selective use of transponders, where the number required exceeds the number of ICFs available.

b) To selectively release anchor weights to recover buoyant transponders.

These 3 Commands, "ENABLE", "DISABLE" and "RELEASE", may be selectively and securely transmitted because each transponder is allocated a unique "address". The command and Address is encoded as pulse intervals using another "common" frequency, DCF, the "DMT Command Frequency".

3.5 *Relay or "Sing-around" Mode*

In conventional low-frequency systems a single frequency, usually 11.0kHz, is reserved for interrogating a "Relay Transponder" mounted on a submersible or other mobile targets *(Ref. 4)*. When interrogated on the relay frequency this would reply on 9.0kHz, the CIF of the system, thus interrogating all the seabed transponders *Fig. 2*. Hence ranges can be measured directly from the ship to each seabed transponder in the first ranging cycle, using the CIF interrogation from the ship. In the second cycle, interrogating on 11.0kHz, the range from the ship to submersible is measured directly, and the indirect "sing-around" relay replies from each transponder allow the ranges from submersible to each seabed transponder to be deduced. Both the ship and submersible positions may then be computed.

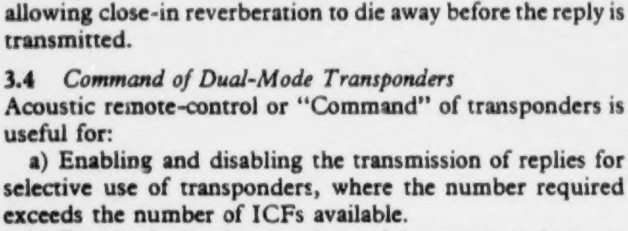

Fig. 2
Significant features of Relay "Sing-around" Interrogation

In the MF system, as many transponder channels as required may be allocated as "Single-Mode Relay Transponders" or SMRTs. Each would be interrogated on its ICF and replies, not on CRF but on CIF, thus interrogating the seabed transponders.

3.6 *Small Transponders in the MF System*

Miniature and Sub-Miniature transponders have been developed using the standard ICFs, but only as single-mode conventional or relay transponders, and with reduced power and life compared with DMTs.

4. Limitation of Conventional LBL Navigation

The main limitation of a conventional LBL system, such as the MF Rangemaster, is the lengthy operation needed to lay the seabed transponders and calibrate the array. An array can be calibrated on a purely relative basis in which case a local grid is devised and the array "self-calibrated". Alternatively, an array can be calibrated with the aid of the surface positioning system into an "absolute" grid such as Universal Transverse Mercator (UTM).

Four methods are normally used:

a) "Boxing-In"
b) Baseline Crossings
c) Iteration from simultaneous surface/acoustic measurements
d) Direct Baseline Measurement

4.1 *"Boxing-In"*

The absolute position of each transponder is established by taking a series of simultaneous acoustic slant range measurements and surface positions as the vessel slowly moves around the transponder. Provided the depth of the transponder is known it should be possible to determine the transponder position to within ±2m in typical North Sea conditions. However, any short term fluctuations in the surface navigation system will introduce errors to each transponder position, and the relative accuracy of the array will not be as good as methods which achieve a best fit using acoustic data. This method is, however, comparatively quick, and an array of 4 transponders on a 1km grid should be calibrated within 3-4 hours.

4.2 *Baseline Crossings*

Slant Range measurements are taken to two transponders defining each baseline as the survey vessel slowly moves across the baseline. Provided the depths of each transponder and the interrogating transducer are known, all measurements can be reduced to horizontal ranges and the baseline computed. The computed baselines are then used in an adjustment program to position the transponders relatively to each other within the local grid to achieve a best fit of the acoustic data. This method can be combined with boxing-in if an absolute calibration is required. The method is time consuming with a 4 transponder array calibration typically taking from 4-6 hours. Inaccuracies will be introduced due to any errors in reducing the slant measurements to horizontal ranges due to ray bending associated with variations of the acoustic propagation velocity with increasing depth.

4.3 *Iteration*

Sufficient simultaneous measurements are taken of the vessel surface position and the range data to each transponder from a number of points within the array selected to give a good geometric coverage. This data is then used in a computer to iteratively compute the absolute co-ordinates of each transponder. The underlying principle of this calibration computation is to allow all the transponders positions and surface position to be adjusted until transponder co-ordinates are derived that best fit the input data according to some best fit criteria. This method gives an absolute calibration which is generally within ±2m. It takes a similar amount of ship's time as the Boxing-in method but it is subject to scaling errors if the sound velocity is not measured accurately.

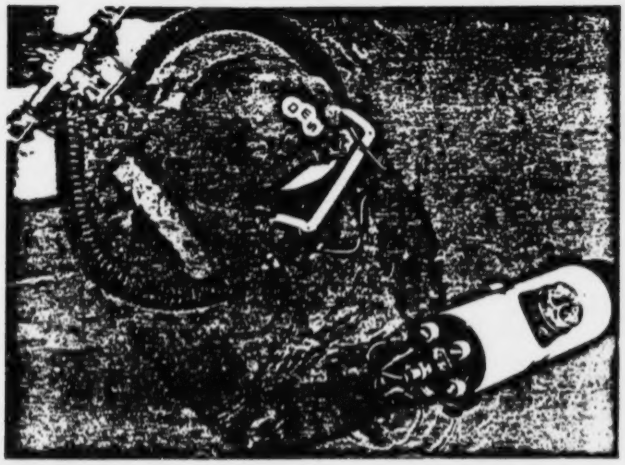

Fig. 3
Direct "Sequential" Baseline Measurement with Diver Operated Rangemeter.

4.4 *Direct Baseline Measurement*

Accurate self-calibration of an array (within ±0.25m) can be achieved if the baselines are measured directly between each transponder. This will overcome any errors introduced by propagation changes which effect slant range measurements. This method has been used during diver based surveys when the diver uses the Rangemeter *(Fig. 3)* to "sequentially" measure each baseline *(Ref. 2)*. It has also been used during accurate ROV debris surveys in the North Sea close to production platforms. In this case the "slave" interrogation transducer installed on the ROV *(Fig. 4)* was positioned adjacent to each transponder transducer in turn, and "simultaneous" ranges obtained to the remaining transponders in the array. However, both methods are slow, and costly in terms of ship and diver/ROV time. Measurements also cannot be easily checked, and any subsequent transponder movement would go undetected.

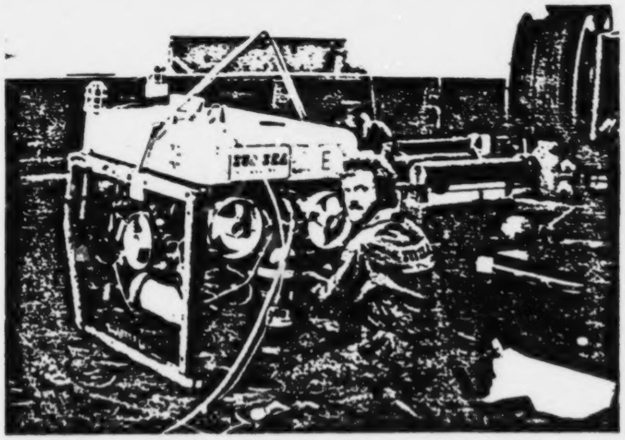

Fig. 4
Direct "Simultaneous" Baseline Measurement with a ROV
(Note: "Slave" Transducer and Emergency Relocation Transponder)

5. Compatt — The "Intelligent" Transponder

The dream of LBL users has thus long been for a system where the transponders would calibrate themselves instantly, after deployment. This problem poses many technical difficulties and has been solved by some manufacturers using "sing-around" techniques whereby baseline distances between transponders are inferred from measurements made at the surface vessel of the combined distances: ship to transponder A, transponder A across baseline to transponder B, transponder B back to ship. This is an indirect method, and the measurements are liable to errors due to sound velocity variations in the ship-to-seabed paths. Sonardyne therefore set about devising a transponder which could directly measure at seabed level the baseline distance to other transponders, and communicate the readings to the surveyor on the ship without corruption or loss of accuracy. This requires of each transponder:

a) The ability to respond to a larger vocabulary of commands to control measurement of each baseline.

b) The ability to act as a "sequential-mode" interrogator to measure each baseline separately.

c) The ability to telemeter the range reading back to the ship.

d) The ability to be used in various other measurement modes, such as LBL positioning.

The required functions were achieved by incorporating a low power microprocessor into the transponder and allowing it to:

a) Decode commands received.
b) Control transmission frequencies and delays.
c) Control receivers and measure ranges.
d) Format and transmit data digitally.
e) Reply to interrogations and control the release mechanism as in a conventional DMT.

This flexibility of operation in an instrument which has to be both robust and portable, has only been possible since the advent of the low power microprocessor, because a great deal of logic is carried out by firmware instead of dedicated hardware. A set of hardware, components such as acoustic transmitters, receivers, timers and interfaces can be designed to be used by the firmware in any order required by the application.

The first "intelligent" microprocessor controlled transponder, the Compatt (Computing and Telemetering Transponder) was introduced in 1979 for operations in Chevron's Ninian Field with OHP Ltd. Compatts use the same CIF, CRF and ICFs and DMTs, but have their own Command frequency, CCR, "Compatt Command Frequency". By adding sensors and an analogue-to-digital convertor, the Compatt is also able to make high accuracy measurements of depth and water temperature, essential for determining the sound velocity and hence the accurate scaling of the array. It is normally deployed with anchor weights and flotation collar like a normal transponder *(Fig. 5)*. Important features of the Compatt are:

5.1 *Operates as a Normal Transponder (dual-mode)*

a) Interrogated on CIF — replies on ICF (simultaneous interrogations for Long-baseline navigation).

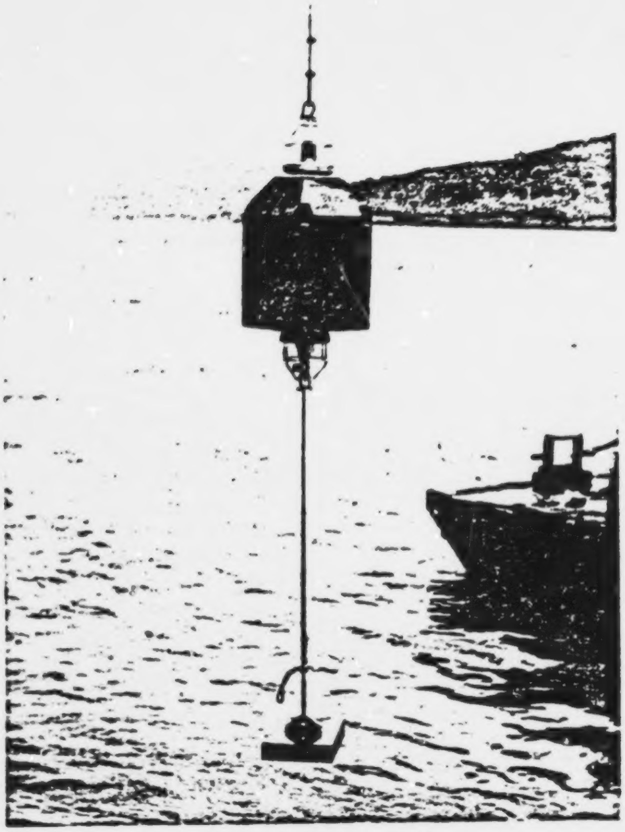

Fig. 5
Compatt Deployment.

b) Interrogated on ICF — replies on CRF (sequential interrogation for array calibration, baseline measurements, and high accuracy linear measurement).

5.2 *Enable/Disable Commands*

A Compatt may be "DISABLED". This prevents it replying to transponder interrogations and prevents acceptance of a "RELEASE" command. When a Compatt, which will not be used immediately, is deployed on the seabed, disabling it will help to conserve battery life. Also, if other transponders with the same ICF are close by, disabling those not in use will prevent interference. When required for use again, an enable command "ENABLES" the Compatt.

5.3 *Release Command*

Compatts fitted with a release mechanism may be commanded to release from their anchor weights. The Compatt must be in the enabled state or the command will be ignored. A high security is necessary for this Command to prevent inadvertent release. This is achieved by requiring three separate release commands to be received within a preset time.

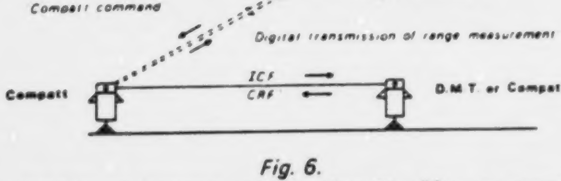

Fig. 6.
Significant features of Direct Baseline Measurement

5.4 *Direct Baseline Measurements (Fig. 6)*

A Compatt can be commanded to measure the direct seabed ranges to another transponder. It is commanded to transmit an interrogation signal on the ICF of the selected transponder which may be another Compatt or a DMT. The transponder replies on CRF which the Compatt receives. The transmission time between the interrogation and reply, which includes the transponder turnaround delay, is measured in the Compatt and telemetered to the ship (or submersible).

Accuracies within 0.25cms can be expected, provided the velocity of sound on the seabed is accurately known.

5.5 *Measurement of Temperature and Depth*

Compatt can be fitted with temperature and depth sensors. It may be commanded from the surface to measure either of these parameters and transmit the information digitally to the surface unit. Accuracies are conservatively 0.2 degrees C and 0.2% of depth.

5.6 *Battery Check*

Each time Compatt performs a function it records the amount of battery charge used in memory and on receipt of the appropriate command it transmits the total amount of battery usage. In this way, it is possible to keep a theoretical check on how much battery capacity has been used, and how long the Compatt may continue to operate before the batteries are exhausted. Compatts fitted with re-chargeable batteries have an extra command to reset the battery usage memory to zero after charging.

Compatts fitted with a release unit will automatically stop replying to interrogations when their battery capacity is almost exhausted. They will still reply to commands, however, so they may be released before the batteries are completely flat.

5.7 *Telemetry Data Rate*

The information sent from a Compatt to the surface unit is in the form of a string of data pulses. The number of pulses per second is called the telemetry data rate and can be remotely selected from SLOW, MEDIUM or FAST to allow for different acoustic conditions.

5.8 *Addresses*

The address of a Compatt is used for the command function and consists of three or four digits. The last two digits represent the frequency (CIF Channel Number). Thus Compatts with addresses 112 and 312 both operate on ICF Channel 12, but can be individually commanded. Normally, only one of these two would be ENABLED at any one time to avoid interference during LBL navigation.

It is possible, therefore, to have up to 256 Compatts in the same area, each individually commandable.

5.9 *Operates as a "Remote Interrogator"*

A major application of Compatt is to act as a "Remote Interrogator", and on command measure the direct ranges from, say, a pipeline pulling head to an array of seabed transponders, and telemeter the ranges back to the lay-barge or survey vessel. This overcomes the limitations of the relay transponder method. If the Compatt is equipped with a depth sensor it can also monitor the depth of the pulling head as it is lowered towards the target area on the seabed. Using specially developed versions of the Compatt firmware the command process has been significantly speeded up for this application. For example, measuring the water depth at the "Remote Interrogator", and ranges up to 500 metres to two seabed transponders takes approximately 10 seconds.

6. 'PAN' — The Universal Controller for the MF System *(Fig. 1)*

The Programmable Acoustic Navigator (PAN) is a microprocessor-based acoustic transceiver for use on ships, or in a manned submersible, in conjunction with any or all of the aforementioned instruments for:

a) Transmission of Commands to DMT or Compatt for Enabling, Disabling, Release, Auto-Calibration and acquisition of depth, temperature or other sensor data.

b) Interrogation of any transponder in simultaneous or sequential modes and measuring slant ranges to any unit.

c) Receiving and encoding data telemetry transmissions from Compatt or other PAN units installed in ships or submersibles.

d) Communicating with controlling devices such as terminals or computers by a variety of accepted interfacing techniques.

e) Computing and displaying positions.

As with the Compatt design, this flexibility is possible since the advent of the microprocessor because the major part of the operational logic of PAN is carried out by firmware instead of dedicated hardware. For example, scaling of measured data to engineering units is a simple matter for a microprocessor, and extra facilities can usually be added by changing the firmware.

Important features of the PAN are:

6.1 *Long-Baseline Navigation*

PAN operates as an advanced acoustic transceiver, measuring ranges to seabed transponders (Compatts or DMTs) and passing the data to a separate computer for position computation. The number of ranges passed to the computer is limited only by the number of filter channels within PAN and the number of transponders on the seabed.

The front panel display will show up to four ranges selected by the operator, though up to 15 ranges may be recorded internally. These ranges may be displayed in any required units if the operator enters a scaling factor (*e.g.* sound velocity if displayed value is required in metres). The default units for the ranges is milliseconds. Ranges passed to the computer are raw two-way travel times suitable for data logging, and for computation.

6.2 *Dual Transducer Ports*

Two transducer connectors are available, selected under firmware control. This is useful during ROV operations with one port connected to the ship's dunking transducer and the second port to a remote transducer deployed on the ROV.

The two ports have also been used with two separate dunking transducers deployed to form a short-baseline on a large semi-submersible crane vessel during a jacket installation.

6.3 *Command of Compatts*

PAN acts as the surface control unit for the transmission of commands to Compatts and the reception and display of the reply. Compatts reply to all commands with an acknowledgement and a data value where appropriate. PAN displays the reply, scaling the data where necessary. Errors detected in the Compatt reply are also listed.

6.4 *DMT Commands*

Dual Mode Transponders (DMTs), when fitted with a command decoder, respond to "ENABLE", "DISABLE" and "RELEASE" commands which can be transmitted from PAN. Audible feed-back of command acceptance is registered by PAN.

6.5 *RovNav Commands*

PAN sends commands to Sonardyne's RovNav submersible mounted measurement system via a modem unit connected to one of PAN's two serial ports, which transmits the commands down the submersible's umbilical (1 core + earth needed). Power is supplied to RovNav either from the umbilical or from batteries on the ROV. *(See Section 11.1.)*.

6.6 *Command of Template Positioning System (MicroNav)*

PAN can send commands and receive replies from Sonardyne's MicroNav Template Position Monitoring Equipment either via an acoustic link or via a modem unit if an umbilical link is required. *(See Section 11.3.)*.

6.7 *Combined Acoustic Transceiver/Computer*

PAN operates as a combined transceiver and computer allowing position and calibration computations to be carried out within a single unit. Position computation is limited to four transponder ranges. This operating mode is required for manned submersible applications *(Fig. 7)*.

PAN can also be controlled from a master computer via an RS232C serial data link or IEEE-488 *(Fig. 7)*. This allows the measurements made by PAN to be used in complex calculation routines, such as auto-calibration of a transponder array from seabed baseline measurements. Experience suggests that survey contractors prefer this option to PAN operating as a combined transceiver and computer since it provides the flexibility which most offshore operations demand, it being quicker to modify computation/display routines written in the high level language of a desk top computer such as the HP9845.

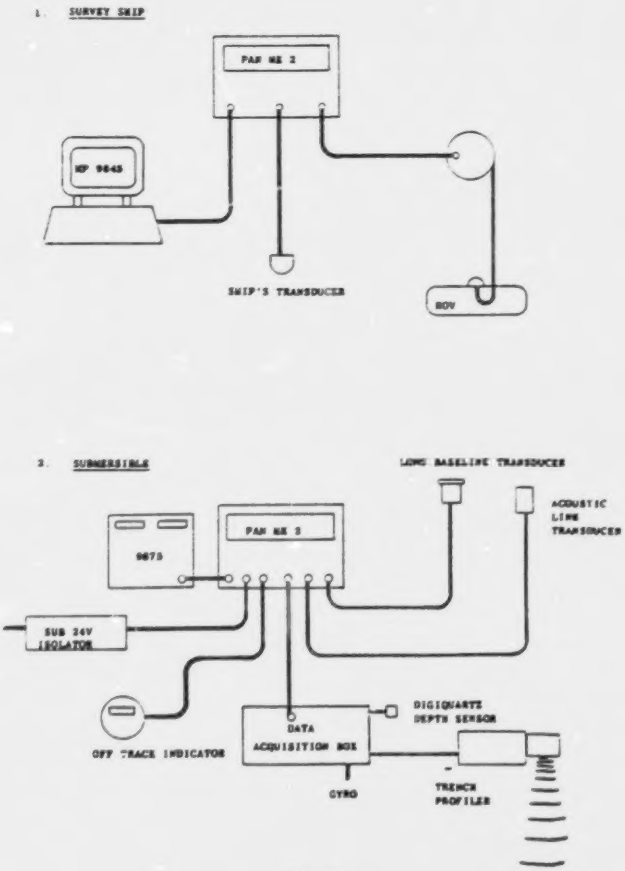

Fig. 7
Typical PAN Installation.

effect is more important and applies to shallow storm waters where water movement can entrap air, and also to estuaries where decaying matter gives rise to gas which gets taken into solution. Use of Medwin's equation will give rise to errors in these situations. The equation can, however, be applied in offshore conditions, particularly below the thermocline and at depths where the high pressure reduces aeration problems.

By differentiation of Medwin's equation and ignoring second order effects, the following relationships can be established:

$$(dv/dT)_{s,D} = 4.6 - 0.11T$$

$$(dv/ds)_{T,D} = 1.34 - 0.01T$$

$$(dv/dD)_{s,T} = 0.016$$

The water temperature can be measured using a platinum resistance thermometer incorporated in a Compatt to an accuracy better than 0.2°C, and the depth measured to an accuracy within 5 metres using a strain gauge sensor. Salinity is established using a salinity probe or from standard Tables, and an accuracy of 0.5 ppt is reasonable. Thus for a typical water temperature of 10°C the propagation velocity can be established to better than 0.9 metres/second (1 part in 2×10^3). This is sufficient to obtain baseline accuracies within 0.5m for 1km arrays of Compatts.

9. Typical Application of PAN/Compatt System

Since its introduction in 1979, PAN/Compatt microprocessor-based systems have been used for the following applications by various survey contractors:

a) Pipeline Laydown Operations.
b) Loading Buoy Installation.
c) Jacket Emplacement.
d) Positioning of ROVs during survey operation.
e) Positioning of a Manned Submersible during survey operation.
f) Positioning of Divers during survey operations.
g) Burial Sledge Position Monitoring.

The following sections discusses the application and advantages of a PAN/Compatt positioning system for a typical pipe laydown operation.

Previously, this has normally been carried out by positioning the lay-barge by surface navigation and calculating the pipe position from catenary plots. This may be adequate in shallow water, but in order to hit the small target areas (typically 2 × 2m) now being specified in increasing water depths, a direct measurement of the pipe flange position is essential.

A Deadman Anchor (DMA) is used to tension the pipe to avoid buckling of the first section, and the following information is normally required by the barge contractor:

a) Position of the dead man anchor.
b) Position of the pipe termination.
c) Orientation of the pipe flange.

9.1 Array Calibration

Before the lay barge approaches the area, an array of four releasable Compatts is deployed (C1, C2, C3 and C4). At least two of these should be fitted with temperature and depth sensors. The velocity of sound is calculated from temperature and depth data, and the six transponders baselines measured in each direction. The auto-calibration calculation provides accurate relative positions for each Compatt. If geographical co-ordinates are required, two of the transponders should be positioned using a standard calibration method.

9.2 *Dead Man Anchor (DMA) Positioning*

A DMT is fitted to the anchor, and baseline measurements made to the DMA from each of the Compatts in turn. The DMT should be fitted with a RELEASE unit to allow its recovery independent of the DMA. If the speed of fixing the DMA is important, the DMT could be replaced by a Compatt configured as a "Remote Interrogator". This would speed up the baseline measurements considerably.

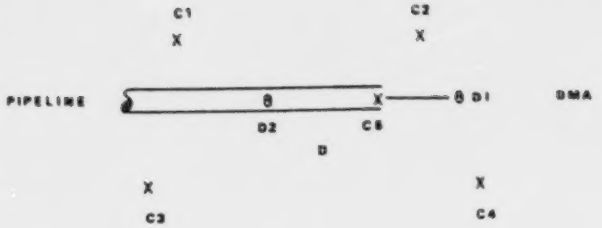

Fig. 8
Pipe Laydown Operation.

9.3 *Pipeline Laydown*

When the DMA has been satisfactorily positioned, the lay barge can move in and start the lay-down procedure. A lithium battery Compatt, configured as a "Remote Interrogator" C5, is attached to the end of the pipe, at a known position, and a DMT, D2, is fixed about 30-40 metres back along the pipe.

Using C5 to measure the baselines to the other Compatts, the position of the end of the pipe can be monitored from when it leaves the stinger all the way to the seabed, and any position corrections of the barge carried out immediately. This saves costly barge time since back-tracking is eliminated. If C5 is also fitted with a depth sensor, its three-dimensional position can be monitored and touchdown determined when the depth is stable.

Measuring the baselines from the main array Compatts to the DMT on the pipe, D2, and calculating its position using a long-baseline calculation determines the position of D2 and hence the orientation of the pipe and the flange. When the operation is complete, Compatts C1, C2, C3 and both DMTs can be released and recovered. C5 is left in place to determine the length of the spool piece.

9.4 *Long Term Positioning Requirements*

If future work in the area, such as positioning a jacket, entails deploying a second array, Compatt C4 should be left to form a permanent baseline with C5. The future array can be tied into to these known positions to ensure positioning consistency. In this case Compatt C4 should be a non-releaseable type fitted with a lithium battery pack for long life.

This method was recently used by Brown and Root Survey Ltd. during pipelaying for Marathon Oil in the Brae Field *(Ref. 7)*.

10. R and D Implications of Microprocessor-Based LBL Equipment

Earlier sections of the paper have pointed out the improved flexibility and accuracy which the application of microprocessors has bought to LBL equipment. However, the equipment manufacturer has to consider factors other than operational advantages:

10.1 *System Development Time*

If a manufacturer has not been involved with microprocessors before, a significant learning time must be expected before design of boards for a microprocessor controlled system becomes efficient. The division of tasks between hardware and software is not always easy to define. Sonardyne is now producing third generation versions of both surface and underwater systems using microprocessor

7. Compatt Auto-Calibration Trials

Compatts and PAN units were supplied to Italian pipe-laying contractor Saipem in 1980/1981 as part of an integrated Simrad SSBL/Sonardyne LBL system for positional control and tracking of a manned submersible and atmospheric inspection bell. The equipment has been used during inspection and maintenance diving on the Trans-Mediterranean pipeline, and pipelaying in BP's Magnus Field. During the acceptance trials of the system, the auto-calibration mode was evaluated using a 1km array off Sicily in 80 metres of water (Compatt addresses 13, 14, 15 and 16). The six baselines were measured in both directions which provides a useful check on each measurement. This would not be possible if a DMT was used in place of a Compatt in an array.

7.1 *Compatt Deployment*

The drop position of each Compatt was established using an integrated Kongsburg DP Computer, Syledis and Simrad HPR system, and these values used as the initial co-ordinates for the auto-calibration. During the measurements of the baselines, the vessel was held stationary by DP (using Syledis as reference) in the approximate centre of the array.

7.2 *Baseline Measurements*

A 1km baseline between two Compatts can be measured in 4 to 5 seconds. However, it is bad surveying practice to rely on a single measurement, and a number of measurements are normally taken of each baseline, histograms plotted, and the minimum consistent reading selected as the correct value. During the Saipem trials between 4 and 8 measurements were taken of each baseline:

Baseline	Minimum Consistent Value	Calibration Value
13-14	793.2	793.0
14-13	792.8	
13-15	962.5	962.5
15-13	962.5	
13-16	1358.2	1358.2
16-13	1358.2	
14-15	1297.8	1297.9
15-14	1298.0	
14-16	1098.5	1098.7
16-14	1098.9	
15-16	891.9	892.0
16-15	892.1	

(All values in metres based on a computed acoustic propagation velocity 1515m/second)

The calibration values are used in a erray adjustment programme.

7.3 *Array Calibration*

	EASTINGS (metres)		NORTHINGS (metres)	
Compatt No.	Drop Co-ords	Auto-calibrated Co-ords	Drop Co-ords	Auto-calibrated Co-ords
13	1762879	1762889.4	4147970	4147978.9
14	1762097	1762102.1	4148050	4148072.7
15	1762856	1762857.4	4147012	4147017.1
16	1761970	1761966.2	4146991	4146982.6

Initial RMS Error of Array — 5.5 metres (based on drop co-ordinates).

Final RMS Error of Array — 0.1 metre.

The RMS errors were computed using a least squares adjustment method and provide a measure of the "quality" of the auto-calibration. (A more sophisticated method based on variation of co-ordinates has recently been proposed by P. Cross — *Ref. 5*). This form of error analysis is frequently used by hydrographic surveyors to check the validity of their results. An alternative method is to compute the range residuals. For an array with good geometry, the residuals should be within the expected linear measurement accuracy of the equipment. The range residuals for the above data are:

Baseline	Measured Range *(metres)*	Computed Range *(metres)*	Residuals
13-14	793.00	792.90	0.10
13-15	962.50	792.39	0.11
13-16	1358.20	1358.34	-0.14
14-15	1297.90	1298.05	-0.15
14-16	1098.70	1098.58	0.12
15-16	892.00	891.92	0.08

These acceptance trials were carried out in July, 1980, using MkI Compatts. An improved Mk2 design was introduced in 1981, and incorporates many improvements to speed up the auto-calibration routine. Experience by different operators with the Mk2 Compatts show that arrays of up to 6 transponders can be calibrated in under 30 minutes with each baseline being measured at least 10 times.

7.4 *Absolute Calibration*

An auto-calibration process only provides relative co-ordinates for an array. An absolute calibration can be obtained by fixing two transponders in known positions, such as on Well heads or pipeline flanges. Alternatively, two transponders in the array can be fixed absolutely using a standard integrated acoustic/surface calibration method or by "boxing-in". If the boxing method is used, one of the transponders is normally considered as "fixed" for the auto-calibration. The bearing of the second boxed-in transponder from the first is calculated and fixed, but the distance between the two set to the measured acoustic baseline length. This procedure will produce the best estimate of the second transponder's position. When calculated this should also be considered "fixed" for the calibration calculation. The absolute accuracy of an array calibrated in this manner will be significantly lower than the relative accuracy.

8. Determination of Sound Velocity

The critical factor in making accurate underwater acoustic measurements is the accuracy with which the propagation velocity can be established. This parameter acts as a scaling factor for an array calibration, expanding or contracting it, without changing its shape.

The sound velocity can be determined from measurements of the temperature, salinity and depth of the transponders and a suitable equation has been published by Medwin *(Ref. 6)*.

$$v = 1449.2 + 4.6\,T - 0.055\,T^2 + 0.00029\,T^3$$
$$+ (1.34 - 0.01\,T) \times (S - 35) + 0.016\,D \text{ m/sec}$$

T = Temperature °C : S = Salinity ppt : D = Depth in metres

$0 < T < 35\,°C \qquad 0 < S < 45$ ppt

$0 < D < 1000$ metres

This equation can be used to compute the velocity to an accuracy of 1 part in 10^4 in 'normal' sea water. However, the propagation velocity is basically related to the compressibility and density of the water, and will change due to the presence of suspended particulate matter and/or aeration. The latter control and a large amount of experience has been gained over a long period of involvement with microprocessors.

Once experience is gained, development times should be somewhat shorter for microprocessor-based systems compared with a similar system based on hardware only. The difference will depend on the system complexity. The more complex the system, the greater the advantage of the microprocessor.

System design is based around two equally important centres, hardware and software. As the software is mainly concerned with the detailed control of the specialised hardware, it is essential for the personnel writing the software to have a detailed understanding of the hardware and conversely, the hardware designers must be aware of the limitations of the software. Both hardware and software engineers must therefore be specialists in microprocessor-based systems.

10.2 *Capital Investment*

A high level of capital investment is necessary if microprocessor-based systems are to be designed efficiently.

A software development system with a fast-access recording medium (hard disc or floppy disc) is essential for design and modification of programs. Most processor manufacturers produce their own development system but, if more than one type of processor is to be used, software development programs are available from several sources to run on standard mini-computers.

The second large investment necessary is for specialised test equipment. Many software development systems now include quite sophisticated de-bugging facilities but in many cases, final fault-finding can only be carried out on the completed system. In this instance a logic state analyser is an invaluable tool and many can now be adapted to run automatic testing under control of a desk-top computer.

10.3 *System Maintenance*

It is generally accepted that the reliability of electronic equipment is inversely proportional to the number of components. As the microprocessor will reduce considerably the number of components for a given system performance, reliability will be improved.

Detailed maintenance in the field is often impossible due to the complex test equipment required. However, if each board in the system is designed to fulfil specific tasks it is reasonably easy to tie a fault down to a specific board. Changing the board will then cure the fault. Diagnostic firmware can also be developed and used by operators to carry out routine maintenance checks, as well as assisting rapid fault finding at a board replacement level.

11. Recent Developments based on Microprocessors

The planned use of the MF band for navigation, command and telemetry, together with the introduction of the low power microprocessor has allowed development of a wide range of compatible acoustic products in addition to LBL systems. This includes ROV based measurement systems (RovNav), short-baseline (SBL), positioning equipment for semi-submersible drilling vessels, installation position monitoring equipment for templates (MicroNav), as well as equipment for precision telemetry applications such as platforms corrosion monitoring and pile grouting monitoring.

11.1 RovNav

Accurate positioning of ROVs has been carried out using LBL techniques with direct range measurements from a "slave" transducer mounted on the ROV *(Fig. 4)*. This is connected by coaxial cores in the ROV umbilical to a PAN on the ship which performs the interrogations and measures the ranges. In practice preamplifiers and matching electronics are required at the vehicle end, and the core requirement frequently exceeds the number of spares available. A separate "acoustic" umbilical has been used and taped to the ROV umbilical, but this increases the overall drag on the vehicle and the handling difficulties. The slave transducer approach is also liable to electrical noise interference, and the umbilical length restricted by attenuation losses.

These problems have been overcome by mounting a microprocessor-based instrument on the ROV, connected by a single twisted pair or coax, to provide an interference-free digital data link with the surface computing equipment. This "intelligent" unit is basically a mini Compatt. The first generation RovNav has been used for accurate sequential linear distance measurement using a directional transducer held in the ROV manipulator. Velocity information and relative height information was obtained from temperature and depth sensors incorporated in the unit.

The microprocessor interprets commands sent from the surface via the umbilical, controls interrogations, measures ranges directly, controls operation of ancilliary analogue sensors, formats all the data and transmits it digitally to the surface via the umbilical. RovNav can be controlled either direct via a host computer, or via PAN.

Future versions of RovNav will include a multi-channel receiver for simultaneous LBL positioning using an omni-directional transducer for interrogating an array of seabed transponders.

11.2 *SBL System*

PAN has been reconfigured as an SBL processor by alterations to the hardware and firmware for positioning a drilling vessel in 150m water depth to within a horizontal accuracy of ±1m and orientation accuracy of ±0.5 degrees relative to two transponders deployed on a well template. The unit operates in conjunction with four transducers mounted below the hull of the drilling vessel.

At 'time zero' the SBL processor causes a tone burst pulse to be transmitted from one of the transducers at the ICF of one of the template transponders. When the pulse reaches the transponders, the transponder replies on the CRF. The times at which this reply pulse arrives at each of the barge transducers is measured and stored by the SBL Processor. As the sound velocity is known these times can be converted into ranges. From the ranges the position of the transponder relative to the drilling vessel can be computed. The next pulse from the transducer interrogates the second template transponder and the ranges from the transducers to this transponder are calculated. These, together with the known distance between the two transponders, are used to compute the second transponder position. The orientation of the drilling vessel is computed from the two transponder positions.

A vertical reference system is required to compensate for the roll and pitch motion of the drilling barge during heavy weather, and for trim and list changes due to changes in ballasting. Rotation of the barge about these axes obviously rotates the relative position vectors and unless compensated for would give an erroneous position. Control and formatting of the roll and pitch data is carried out by the PAN SBL microprocessor. A host computer acts as the overall acoustic system controller, data processor, data logger, operator interface and provides the interface between the acoustic system and the rest of the positioning, graphics and data logging package.

11.3 *MicroNav*

MicroNav has been specifically developed as an installation position monitoring system for templates. This "intelligent" unit is in effect a mini PAN in a pressure housing and has been used for sophisticated underwater measurement and positioning operations for Conoco UK Ltd. on the Hutton Field Tension leg Platform Project *(Ref. 8)*.

Because of its microcomputer capabilities, MicroNav can act as a data acquisition system to collect extra information associated with precision positioning operations as well as range data. The information can be acquired either from analogue sensors, using a digital-to-analogue converter built into the MicroNav, or can be taken in digitally via RS232 or 20mA current loop inputs. The sensors are digitized on command from the surface and the resultant data formatted together with the range data for transmission either via an acoustic telemetry link, or an umbilical.

The following facilities have been incorporated:

11.3.1 *Temperature Sensors*

A platinium resistance thermometer and conditioner circuit measures the water temperature to an accuracy within 0.2°C. This is used to obtain accurate estimates of the sound velocity *(Section 8)*.

11.3.2 *Strain Gauge Depth Sensor*

A semi-conductor strain gauge sensor has in an infinite resolution and a hysteresis of better than 0.1% over the full pressure range. For small excursions about a mean depth, the hysteresis is proportionately lower.

11.3.3 *Digital Depth Sensor*

The MicroNav contains the facility to count the frequency output of a 'Digiquartz' pressure sensor, which claims an accuracy of around 0.02%. The output frequency varies between 40hKz at zero pressure to 36kHz at full pressure, and this is counted over a fixed period by the MicroNav microcomputer.

11.3.4 *Attitude Sensing*

MicroNav is used for precision levelling during installation of seabed structures. It has been fitted with a variety of inclinometers from simple pendulous potentiometer devices with a resolution of 0.3 degrees to servo-accelerometer types with a resolution of a few minutes of arc.

11.3.5 *Height Above Bottom*

An Altimeter (or short-range echo sounder) has been developed for lowering structures into contact with the seabed. This is interfaced via a 4-core cable into the MicroNav.

11.3.6 *Gyro Compass*

MicroNav has been used for precise orientation of seabed structures and an interface provided for a re-packaged version of the Robertson SKR80 North-seeking compass.

11.3.7 *Short-Baseline Navigation Facility*

MicroNav has been used in an "Inverted SBL Mode" for positioning a structure relative to a heavy-life vessel, without the use of a seabed transponder array, and without the use of any permanently-installed acoustic equipment on the vessel *(Ref. 8)*. An arrangement of 3 or 4 transducers at known points on the structure, cabled to the MicroNav, is directed upwards. Under the vessel a single transponder is temporarily attached as a reference marker. As the structure is lowered, the time-differences as the transponder signal arrives at the multiple transducers, together with roll and pitch measurements made by the MicroNav, allow 3 dimensional positioning relative to the vessel.

12. Conclusions

The Sonardyne Integrated Medium Frequency family of underwater acoustic products based on intelligent application of microprocessors is a carefully thought-out system of compatible instruments, with wide capabilities, a proven record resulting from 4 years experience in the North Sea, Mediterranean and Far East, and with ample flexibility to cope with future tasks in underwater engineering measurements for many years. This has only proved possible following extensive development experience over the past 5 years with microprocessors.

13. Acknowledgements

Sonardyne acknowledges the co-operation and positive attitude of oil field operators, survey contractors and individual surveyors and engineers who have recognised the potential and flexibility of a new generation of acoustic positioning systems based on microprocessors.

Abbreviations

PAN	Programmable Acoustic Navigator.
Compatt	Computing and Telemetering Transponder.
DMT	Dual Mode Transponder.
CIF	Common Interrogation Frequency.
ICF	Individual Channel Frequency.
CRF	Common Reply Frequency.
LBL	Long-Baseline.
SBL	Short-Baseline.
SSBL	Super Short Baseline.
MF	Medium Frequency.
LF	Low Frequency.
DMA	Dead Man Anchor.
RMS	Root Mean Square.
ROV	Remotely Operated Vehicle.

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Day 1
Paper 2

TITLE

Acoustic Positioning During Pipelaying of the Brae-Forties Pipeline

prepared for

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by

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August 1982

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SYNOPSIS

The construction phase of the Brae Field Development commenced with the installation of the Brae-Forties pipeline and the Brae 'A' jacket, which were achieved at a distance of up to 88 kilometres from existing installations.

Irrespective of improved 'over the horizon' positioning systems such as Syledis it was demonstrated that the accuracy which could be achieved was not adequate to meet the required positioning tolerances. This situation arose because the pipeline was to be laid prior to jacket placement hence there would be no surface installation from which to reference commencement of pipelay from Brae. Furthermore the installation of the Brae jacket was also engineered for placement within certain tolerances and that if these were exceeded then the dimensions for the spoolpiece could have fallen outside acceptable limits.

It was therefore considered essential to establish some other local reference datum which, by definition, could only be a fixed object on the seabed. In this way the installation of the pipeline and the jacket could be made relative to the fixed object and thereby ensure that prescribed placement and relative offset was achieved. This requirement was best met by a suspended guide base

of the proposed jacket location. Of these wellhead 16/7a-8 was selected as the most suitable and designated as the preferred benchmark.

The law of physics in the marine environment dictates that the only effective means of measurement and hence surveying is by acoustics. Recent advances in this science has created the opportunity to establish and accurately calibrate an array of transponders on the seabed by directly interrogating the array and measuring the travel time between the respective transponders. The results when subject to statistical analysis indicate that the achieveable accuracy is +0.25 m with a least squares standard deviation of 0.1 m. Provided that the orientation of the array is known then the array can be operated as a local grid or integrated with surface navigation or other means to conform with mercator projection.

It is important that care is exercised in establishing the array and due consideration given to its mode of operation in order to ensure satisfactory results. However, experience shows that the systems available are now tried and proven, and therefore were quite capable of meeting the overall objectives.

To this effect Marathon Oil U.K., Ltd is pleased to report that the positioning of the Brae-Forties pipeline, both at the initiation at Brae and final laydown at Forties was achieved within the defined tolerances. In June 1982 the

Brae 'A' platform was positioned to within one metre of the design co-ordinates by utilising the same acoustic net devised for the pipeline operations at Brae.

Introduction

In an oilfield development the design location for a production platform as required for reservoir considerations is rarely critical. However, the situation changes as developments progress into the construction phase at which time it is considered important that the quality of positioning control is assured at an early time, in order to collate the various elements of the platform and associated site investigations.

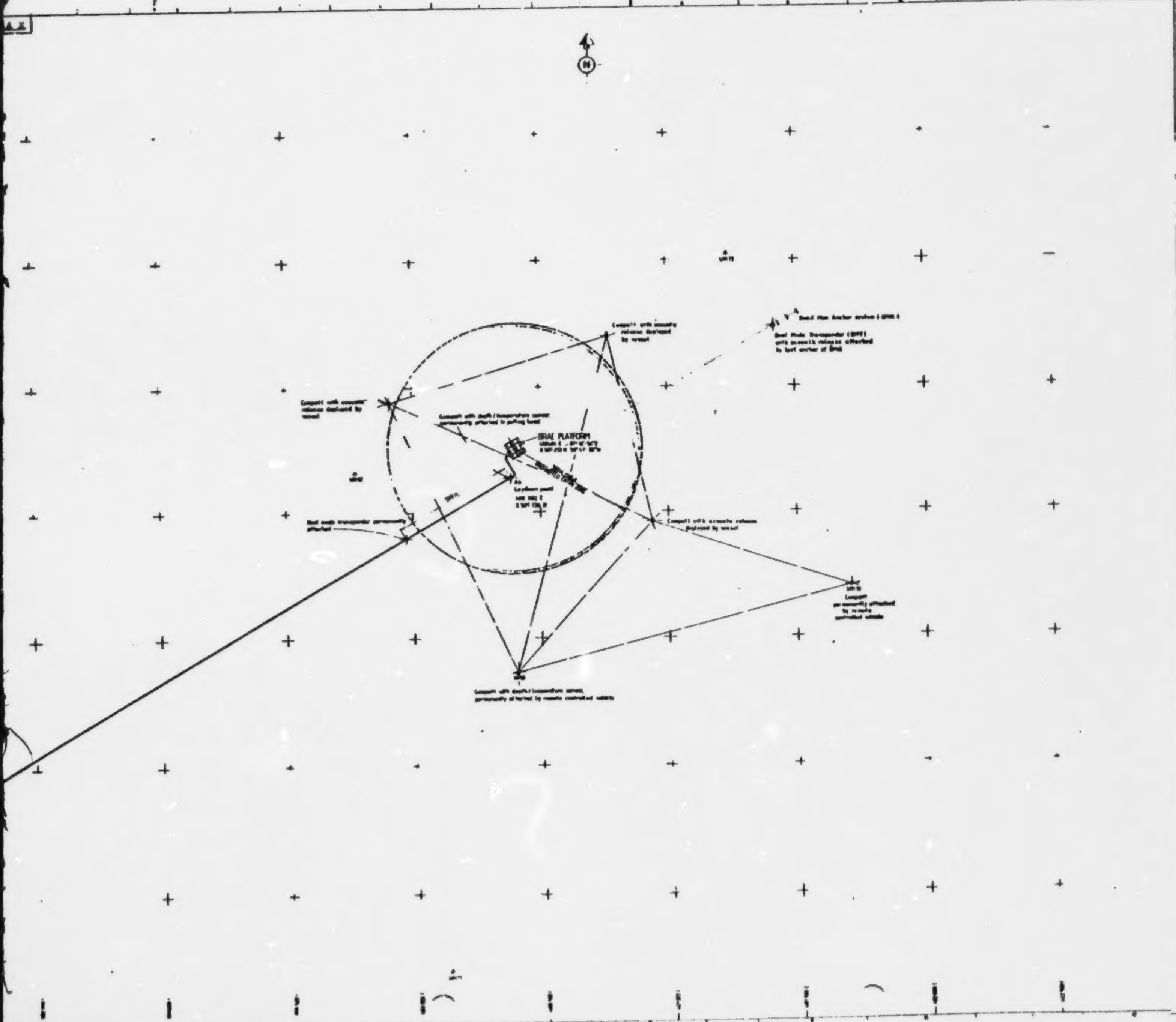
Therefore, the elements of positioning control for the Southern Brae Field Development were established during the site specific geotechnical investigations in May 1979. This involved referencing sat nav co-ordinates of a fixed structure with available radio navigation systems. In this instance the fixed structure takes the form of a subsea guide base assembly in close proximity to the required platform location. Consequently the wellhead provided a local reference datum from which it was possible to ensure that all subsequent operations were compatible.

During this initial period several studies were conducted to improve the overall knowledge of those areas considered to require particular attention. This included a visual inspection by unmanned submersible of the wellhead, platform site and the proposed approach areas for the Brae-Forties pipeline at both Brae and Forties.

Pipelay at Brae

The location of the Brae 'A' jacket was designated as centred 2900' grid north of the 16/7a-8 wellhead location and orientated 30 degrees anticlockwise (330 degrees grid). In order to accommodate the specified tolerances of jacket placement (10 metre radius with rotation of plus or minus 5 degree from 330 degrees), the laydown head and orientation of the Brae Forties pipeline at Brae approach was designed accordingly. This was engineered to accommodate a Z shaped spoolpiece which had to meet the required design specifications such that the tolerances for the laydown head were limited to an area of 3 metre radius.

The tolerances so indicated are not within the scope of radio navigation positioning capabilities given the extended ranges from existing installations. It was for this reason that an array of acoustic transponders referenced to 16/7a-8 well location was advocated. In this way the required accuracy as well as real time positioning control could be assured. The type of transponders selected represented 'state of the art' intelligent units, Compatts. These are capable of making direct horizontal range measurements and thus overcome problems relating to slant range measurements through the water column which are subject to inherent problems in propogation effects. Prior to pipelay an extensive array of transponders was placement of transponders on guide frames of wellheads 16/7a-8 and 16/7a-10. Those units which were to be permanently attached to the wellhead and the pipeline were fitted with lithium batteries to provide an operating life of up to two years subject to usage. Hence this arrangement not only provided a reference for the pipelay at initiation but also formed the basis for positioning control of the Brae 'A' jacket which was scheduled for the following year. To effect the permanent installation of the two transponders on the wellheads two frames were fabricated that could be placed on the top of the guide-posts by unmanned submersible. This arrangement eliminated any requirement for diver support during this phase of the operation. The entire array was then calibrated by taking ranges, which are measured as two way travel time in milliseconds, from each of the transponders to all other units. This was possible by using an interrogating dunking transducer deployed from the survey vessel to command a particular Compatt transponder (maximum 32 addresses each with one of 8 distinct frequencies) to take ranges to other specified transponders. In this manner a comprehensive network of 2 way ranges could be established in a relatively short time. The computation to determine the range between two transponders is dependent on the knowledge of the propagation rate. Propagation of sound in seawater has been much studied and various empirical formulae have been devised, each of which will give a slightly different velocity for given inputs of depth, salinity and temperature, and hence great care should be exercised to ensure that the best estimate is achieved.


N
BRAE PLATFORM
Laydown point
Compact with acoustic release deployed by vessel
Compact with depth/temperature sensor permanently attached to pulling head
Compact with acoustic release deployed by vessel
Compact with depth/temperature sensor, permanently attached by remote controlled vehicle
Compact permanently attached by remote controlled vehicle
METRES

LEGEND

NOTES

WELL-HEAD CO-ORDINATES				
	UTM		GEOG	
[illegible]	NORTHINGS	EASTINGS	NORTHINGS	EASTINGS
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 1

Marathon Oil U.K. Ltd.

BRAE-FORTIES PIPELINE
BRAE APPROACH DETAILS

1000

An autocalibration program was used to reduce the data which for a 5 transponder array was able to provide a standard deviation of 0.25 metres over ranges of up to 1200 metres. It should be noted that great care was exercised to ensure that line of sight was achieved between all transponders as even small undulations in seabed topography over these distances can create masking effects. This was achieved using buoyancy collars on the transponders and deploying the units on clump weights with 5 metre strops.

The next objective was to integrate the acoustic array to the surface navigation systems. It has already been mentioned that the position of the wellheads was known from 3D sat nav fixes and that studies during the site investigations had indicated that the position given correlated within acceptable limits with the surface navigation systems such as Syledis. Further calibration measurements were made using the "box in" technique whereby the vessel encircled the transponder at a range of 500 metres taking continuous slant range readings. Once reduced these readings enabled the acoustics and the surface navigation system to be directly referenced. It was determined by the "box in" procedure of the transponders on the wellheads that good correlation existed with regard to wellhead 16/7a-9 but there was an offset of

20 metres with respect to wellhead 16/7a-10. Calibration in this respect was necessary in order to establish the azimuth for the array. Additional checks were made on the positions of other transponders in the field by "box in" technique, and so that the azimuth of the array was eventually determined by keeping the position of wellhead 8 fixed, and in accordance with the satnav co-ordinates, and rotating the position of wellhead 10 to accommodate the acoustic range as determined between the two wellheads. The results for the final array gave a RMS array error for 6 transponders of 0.08 metres which demonstrated the overall feasibility of the method. It is worth noting that the integration of the surface navigation to a local datum is considered important as the acoustics real time update is approximately 30 secs or longer and except for barge control is rarely fast enough for surface control of operations such as anchor handling.

The first phase of the pipelaying operations with the layaway commencing at Brae involved setting a dead man anchor (D.M.A.) incorporating an abandonment and recovery wire some 1500 metres from the laydown point. In order to ensure accurate placement of the laydown head and correct alignment of the pipeline for the first 1000 metres it was essential that the D.M.A. was laid along the same alignment as the proposed pipeline, namely 60 degrees grid. This would then place the pipeline at right angles to the prescribed jacket orientation of 330 degrees grid.

This was achieved by fixing a Dual Mode Transponder (DMT) to the D.M.A. system. The system was lowered to the seabed suspended between two anchor handling tugs and the required position was established by interrogating the DMT from at least three of the transponders in the acoustic array. It was necessary to ensure that the tugs were held on the correct bearing during deployment of the array otherwise there was little difficulty in ensuring its accurate placement and orientation.

A similar operation was used during pipeline laydown and initiation. Having identified the laydown area as a target of three metre radius the pipelay barge, Semac I set up position over the laydown location on a 12 point mooring. From this position the barge was able to recover the abandonment and recovery wire (A/R wire) attached to the D.M.A. and connect it to the pipeline laydown head.

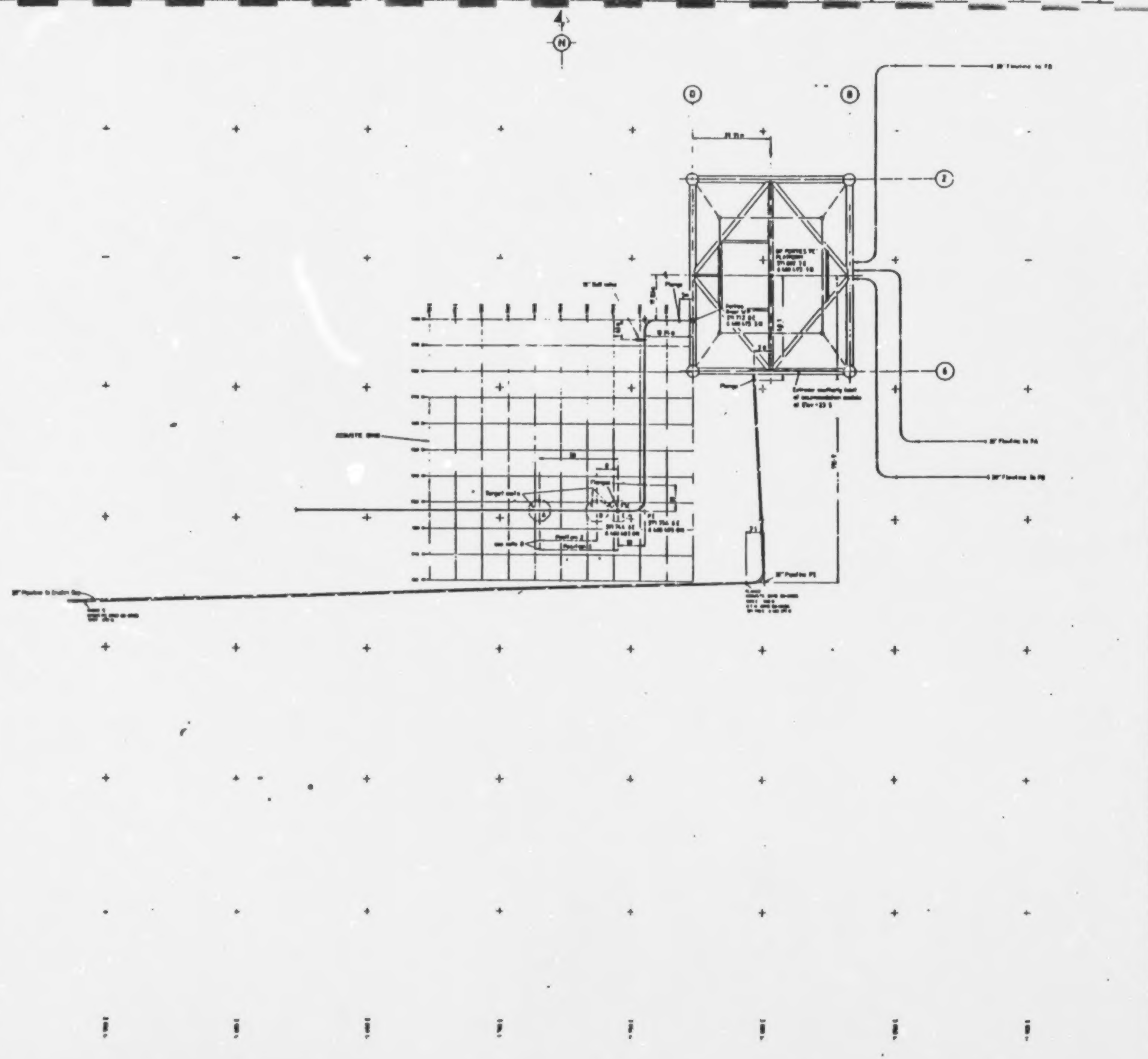
The intention was to use an A/R wire of known length (prestressed) which could be adjusted accordingly so that as the laydown head is drawn now onto the seabed under the prescribed tension it would fall at the correct position. In the event, the prestressed distance of the wire was not known and a alternative method was used. This involved manoeuvering the barge over the laydown head by means of a transponder deployed from the clump weight of the diving bell suspended beneath the barge. By applying the appropriate offsets it was possible to calculate the required dimension of the A/R wire so that it could be cut to the correct length. In order to ensure accuracy of placement a transponder was attached to the laydown head so that its position during deployment could be continuously monitored.

Interrogation of the transponder on the laydown head after pull away showed that the centre of the Cameron hub at the laydown position had been laid to within 1.2 metres eastings and 0.6 metres northings of the prescribed target location. The position fix was given by five ranges from the co-ordinated array and S.D.of 0.4 metres was achieved. A further DMT was placed on the pipeline at KP (Kilometre Post) 0.5. Monitoring of its position confirmed that the pipeline during the initial lay was along the prescribed bearinq. Throughout this phase readings were observed on the surface navigation systems so that following the deployment of the DMT at KP 0.5 the changeover of primary pipelay positioning control could be easily effected.

Pipelay at Forties

The Forties approach for the proposed pipeline comprised a long radius curve some 2 kilometres in length which passes into a reversed curve of 2000 M radius from which point the route was designed to run parallel to the existing Cruden Bay pipeline for a distance of 700 metres to the laydown location. This represented the most critical phase for positioning control of the Brae-Forties pipeline, particularly since the radius of curve was approaching the minimum acceptable for a pipeline of this diameter and wall thickness. Furthermore, it was necessary to ensure that the pipeline was laid at an offset of 25 metres from the Cruden Bay line and that laydown was achieved within a 3 metre square target area.

To gain more information for the positioning control at Forties it was decided to carry out an investigation of the existing facilities by arrangement with BP Petroleum Development Ltd. This comprised a survey using conventional transponders consisting of a four unit array which was referenced to the Forties 'FC' platform by means of an interrogating transponder deployed from a TREC unmanned submersible. Once the array was calibrated and referenced to the platform it was possible to accurately survey the Cruden Bay spoolpiece and the first few hundred metres of the pipeline. This included conducting an extensive series of measurements at identifiable points on the seabed such as the sealine flange and anodes. The



N
D
B
2
6
ACOUSTIC GRID
Target units
Flange
BP FORTIES 'FC' PLATFORM
30" Flowline to FD
30" Flowline to FA
30" Flowline to FB
30" Pipeline FC
30" Pipeline to Cruden Bay

NOTES

[illegible]

LEGEND

[illegible]

METRES

TABLE 2

Marathon Oil U.K. Ltd.

BRAE-FORTIES PIPELINE
FORTIES 'FC' SPOOLPIECE

series of plotted positions enabled the orientation and position of the Cruden Bay pipeline and spoolpiece to be accurately determined and thereby establish the required position of the Brae-Forties pipeline at the specified offset of 25 metres. It was appreciated that with a pipelay catenary of nearly 400 metres in order to ensure that the newly laid pipeline was maintained at the correct offset, some means would have to be devised to monitor the touchdown point throughout the approach into Forties 'FC'. In practical terms this was only possible using acoustics. It was, therefore, decided to utilise a staggered array of 7 transponders which would included installation of at least 3 transponders on the Cruden Bay pipeline in order to provide a direct positioning reference. The array was devised in the configuration shown in the attached drawing in order to give the best possible facility for three range fixing and still provide some order of redundancy if any of the units failed. In addition the array was extended to the west and north for a distance of 2.5 kilometres to enable the changeover from surface navigation to primary acoustics for the approach and laydown at Forties to be effected as soon as possible.

Provision was made to attach transponders on the pipeline at regular intervals in the last 2 kilometres and to monitor touchdown by means of unmanned submersible with a MicroNav system. The MicroNav system is designed for use with unmanned submersibles to utilise the umbilical as

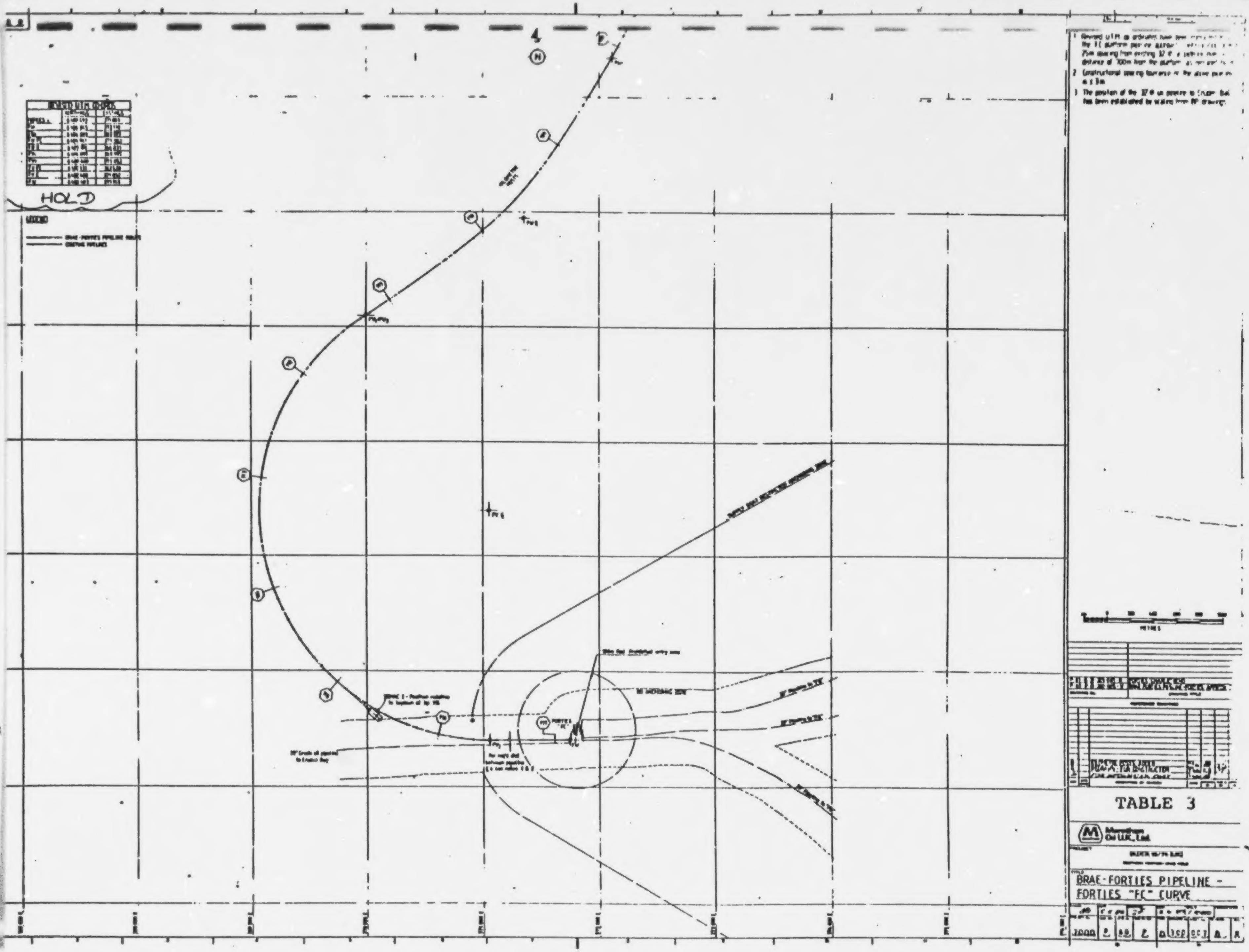

HOLD
METRES
FORTIES "FC"
Marathon Oil U.K. Ltd.
2000
D
R

TABLE 3

BRAE-FORTIES PIPELINE -
FORTIES "FC" CURVE

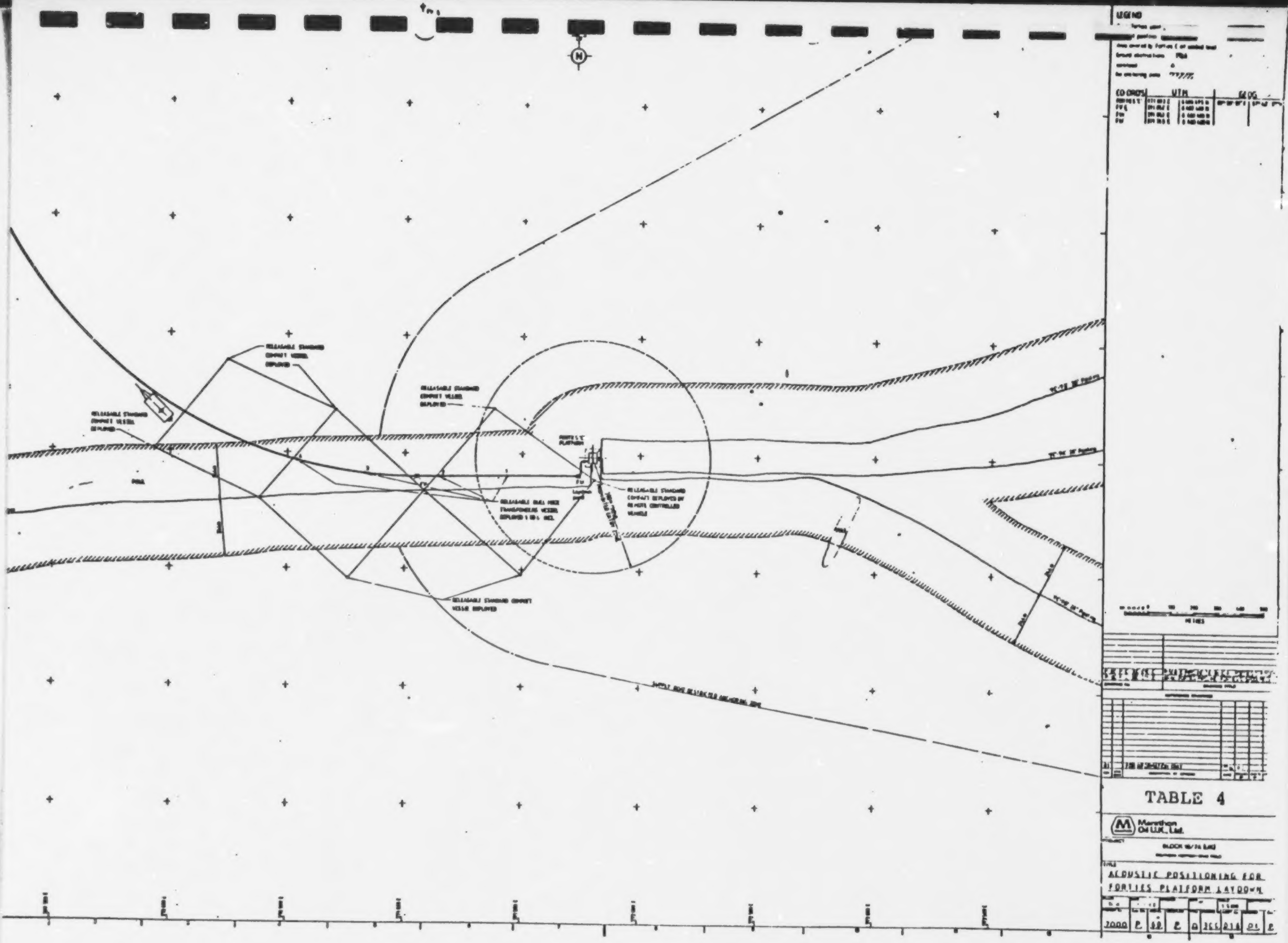

LEGEND
CO ORDS
UTM
GEOG
RELEASABLE STANDARD COMPATT VESSEL DEPLOYED
RELEASABLE STANDARD COMPATT VESSEL DEPLOYED
RELEASABLE STANDARD COMPATT VESSEL DEPLOYED
RELEASABLE DUAL HEAD TRANSPONDER VESSEL DEPLOYED 1 TO 4 INCL.
RELEASABLE STANDARD COMPATT DEPLOYED BY REMOTE CONTROLLED VEHICLE
RELEASABLE STANDARD COMPATT VESSEL DEPLOYED
SUPPLY BOAT RESTRICTED ANCHORING ZONE
METRES
N
2000 E 88 E 0 355 018 01 E

TABLE 4

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ACOUSTIC POSITIONING FOR
FORTIES PLATFORM LAYDOWN

a hard wire telemetry link to the surface. This has the advantage of providing a much faster update rate which is inherently one of the weak factors with any acoustic navigation system. A Scorpio unmanned submersible was selected as being a versatile system which would prove suitable for carrying the micro nav system but unfortunately the vehicle was not retrieved from operations at Brae and was subsequently replaced by a manned submersible spread.

This comprised two vehicles operating back to back which was selected and customised to conduct a complete visual survey of the as-laid pipeline. In addition the system was made available for the final approach to Forties to support the operation. This included conducting acoustic measurements by fixing a transponder to the submersible and flying the unit to positions such as the touchdown point of the pipeline. In particular the manned submersible was used to investigate the seabed in the vicinity of Forties FC including the full extent of the Cruden Bay pipeline for a distance of 250 metre west from the sealine flange to a point where the pipeline becomes buried. This operation was considered desirable as it provided a positive identification of the Cruden Bay pipeline in relation to the calibrated acoustic array.

As with any survey operation of this nature the data processing was of particular importance. The contractor in order to provide real time data processing. A specialised suite of software was formulated for use with a HP 9845B designed to handle the surface navigation systems (Argo and Syledis) and the acoustic inputs from the PAN microprocessor in a sequential format. Whereas in concept the arrangement would have proved ideal for the requirement it placed considerable demand on the 9845 and altogether it was not able to cycle the data at an effective rate.

This situation was overcome by employing another computer to process the PAN inputs in order to provide descriminate data. As with any acoustic system the level of replies proved somewhat variable and the ranges displayed were not always repeatable. For the reason it was important that the processing system was capable of making best use of the available data to ensure continuity of position fixing at regular periods.

Provision was also made to navigate the pipelay barge by acoustics by deploying an interrogation transducer on the diving clump weight throughout the approach to Forties. This was to ensure that the beadstall position on the barge was at the correct position to ensure accuracy of lay. It is worth noting that this position during the final approach was well outside the actual line of lay as a pipeline characteristically falls inside the "bend" of a curve.

Pipelay during the final approach and laydown was effected by interrogation of the acoustic array from the series of transponders located on the pipeline at referenced positions. The respective transponders were sequentially interrogated and although an improved data update is to be preferred the low order standard deviation of the fixing provided the necessary confidence to meet design parameters. This method has the additional benefit of establishing the termination of the pipeline for the attachment of the laydown head; as once a transponder fixed to the pipeline is known to be located on the seabed, it is a simple matter of monitoring the subsequent pipeline laid and calculate the additional pipe required to achieve the prescribed target. The operation proved successful and final lateral adjustment was achieved by manoeuvring the position of the barge as required whilst maintaining continual interrogation of the transponder affixed to the laydown head. During this final phase direct interrogation of the transponders on the respective pipelines was made in order to ensure that the required offset of 25 metres was maintained.

Subsequent surveys demonstrated that the pipeline had been laid in accordance with the design specifications such that hook-up at the Forties end was able to proceed without difficulty.

High Frequency Trials

Long Baseline Configuration

Introduction

The trials took place 22-24 April 1983 in conjunction with CNEXO, near the city of Toulon in the South of France.

1. Range tests in shallow water.

Three Acoustic Transponders (ET 123) were installed in rigid tripod mounts and deployed in 20 meters of water. The distance between the transponders was between 300 and 400 meters.

An acoustic module (AM 123) was deployed from the support vessel, which then slowly steamed away from the transponder array.

The purpose was to determine the useable and maximum operational range of the transponders. The noise level was reasonably typical.

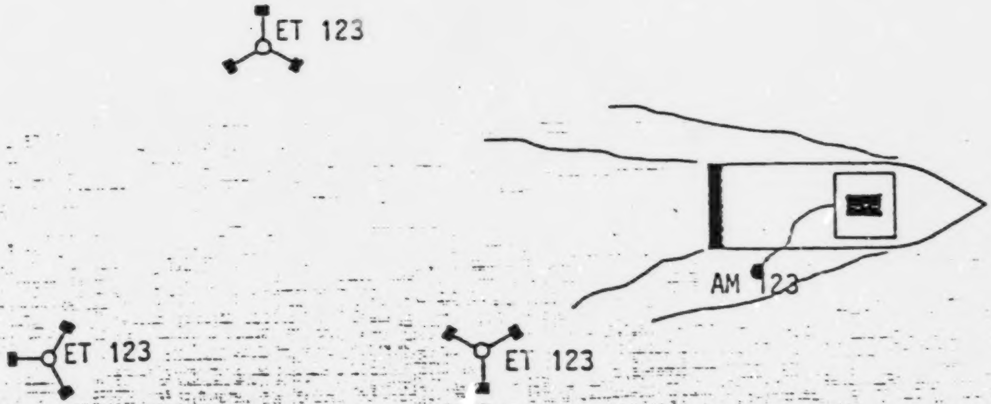
Results:

Response frequencies of the Transponders

	57 kHz	87 kHz	102 kHz
Useable Range	1000	885	800
Maximum Range	1020	1050	920

Useable Range: This was defined as the range at which 80.0% valid replied were obtained

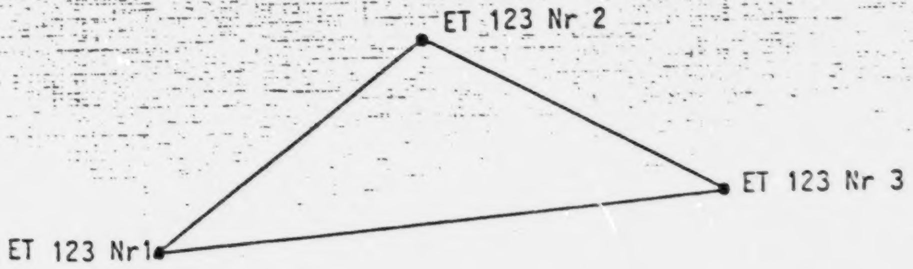
Maximum Range: This was defined as the range at 20.0% valid replies were obtained


ET 123
AM 123
ET 123
ET 123

The vessel steamed back into the transponder array and identical reception results were obtained.

2. Autocalibration of transponder array

The position calculated for a mobile target within the array depends on knowing the coordinates of the reference transponders. Therefore it is important to know these coordinates with a very high degree of accuracy.


ET 123 Nr 2
ET 123 Nr 3
ET 123 Nr1

There are two methods of calibrating the array:

- A least squares calibration requiring movement of the support vessel (and AM 123) through the array.
- A "sing-around" interrogation for which the AM 123 is in a fixed position.

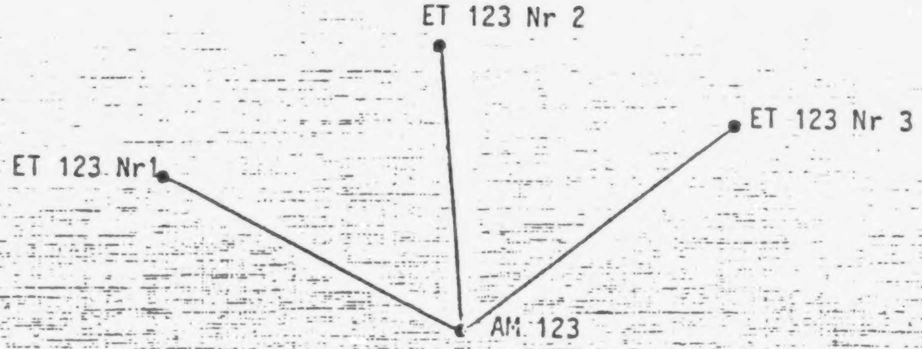
The method chosen here was a "sing-around" calibration. The AM 123 was deployed to the bottom in a fixed mounting.

The AM 123 was used to measure the direct distances (AM-ET) and the perimeter distances (AM-ET_1-ET_2-AM). The values allow the distances between the transponders to be calculated. Each transponder has two distinct interrogation, and two distinct response frequencies, as illustrated below.

	Trans 1	Trans 2	Trans 3
F_1 Interrogation	72 kHz	72 kHz	72 kHz
F Response	57 kHz	87 kHz	102 kHz
F_2 Interrogation	57 kHz	87 kHz	102 kHz
F Response	72 kHz	72 kHz	72 kHz

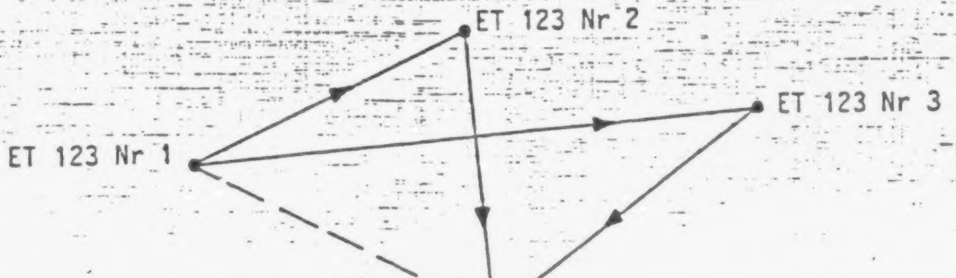
2.1 Description of Procedure

Direct Measurements


ET 123 Nr 2
ET 123 Nr 3
ET 123 Nr1
AM 123

The AM 123 interrogates the field at 72 kHz. The transponders respond at 57 kHz, 87 kHz, 102 kHz, respectively. The distances AM/ET$_1$, AM/ET$_2$, and AM/ET$_3$ are obtained.

Relay Measurements (ET$_1$)

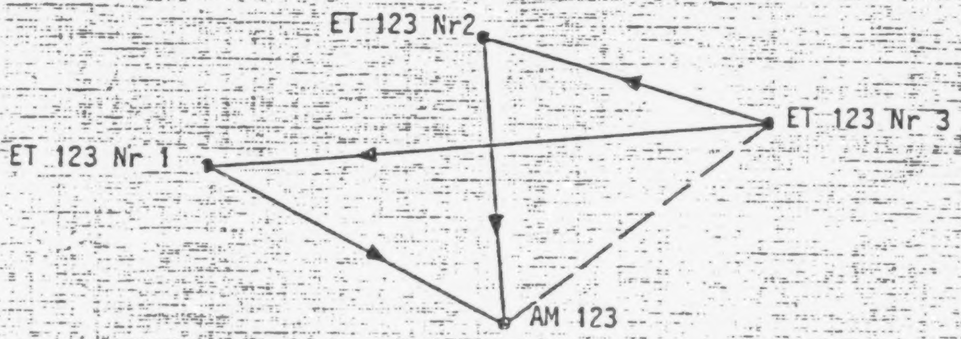

ET 123 Nr 2
ET 123 Nr 3
ET 123 Nr 1
AM 123

The AM 123 interrogates on the second interrogation frequency of Transponder 1, 57 kHz. ET$_1$ will be the "relay" transponder. It responds at 72 kHz, which simultaneously interrogates and causes the two other transponders to reply at their F$_2$ response frequencies, 87 kHz and 102 kHz.

The following distances are obtained:

AM-ET$_1$-ET$_2$-AM
AM-ET$_1$-ET$_3$-AM
AM-ET$_1$

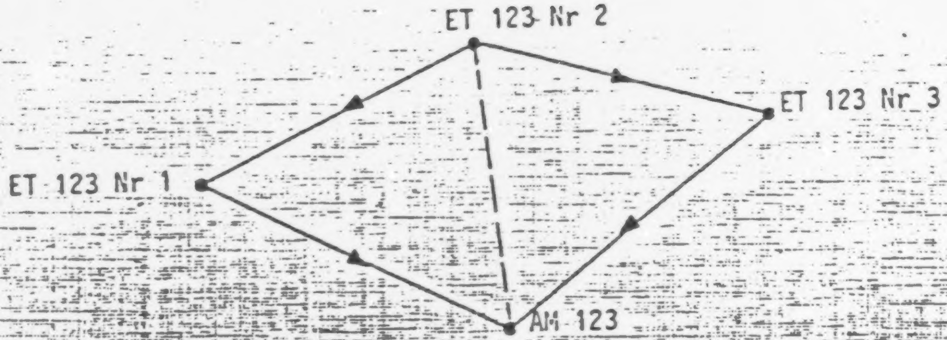
Relay Measurements (ET$_3$)



The same procedure is repeated using ET$_3$ as the relay. (The AM 123 interrogates on 102 kHz.) The following distances are obtained.

AM-ET$_3$-ET$_1$-AM
AM-ET$_3$-ET$_2$-AM
AM-ET$_3$

Relay Measurements (ET_2)



The relay interrogation procedure is used again, using 87 kHz as the AM interrogate frequency. The following distances are obtained.

$AM-ET_2-ET_1-AM$
$AM-ET_2-ET_3-AM$
$AM-ET_2$

This cycle is repeated "N" times (operator selectable). The values are stored in memory and then used in the calibration algorithm.

2.2 Calibration Principle

The distances recorded are:

ET_1-AM
ET_2-AM
ET_3-AM
$AM-ET_1-ET_2-AM$
$AM-ET_1-ET_3-AM$
$AM-ET_2-ET_1-AM$
$AM-ET_2-ET_3-AM$
$AM-ET_3-ET_1-AM$
$AM-ET_3-ET_2-AM$

The following distances can be calculated:

$$(AM/ET_1/ET_2/AM) - (AM/ET_1) - (AM/ET_2) = ET_1/ET_2$$
$$(AM/ET_1/ET_3/AM) - (AM/ET_1) - (AM/ET_3) = ET_1/ET_3$$
$$(AM/ET_2/ET_3/AM) - (AM/ET_2) - (AM/ET_3) = ET_2/ET_3$$

These values are obtained twice each cycle.

After the "N" acquisition cycles, average distances between the transponders are determined.

The origin of the X,Y grid is arbitrarily placed at the position of ET_1, with the X axis running through ET_2.

Results Obtained

Over three separate calibrations a variance of 4 cm on the position of the origin transponder was found.

See annexes 4 and 5.

3.0 Calculation of Position in the Long Baseline

In the same array of transponders the AM 123 was deployed on a special tripod with rotatable arm.

3.1 Repeatability of Measurements

The AM 123 interrogated the three transponders ET_1, ET_2, and ET_3.

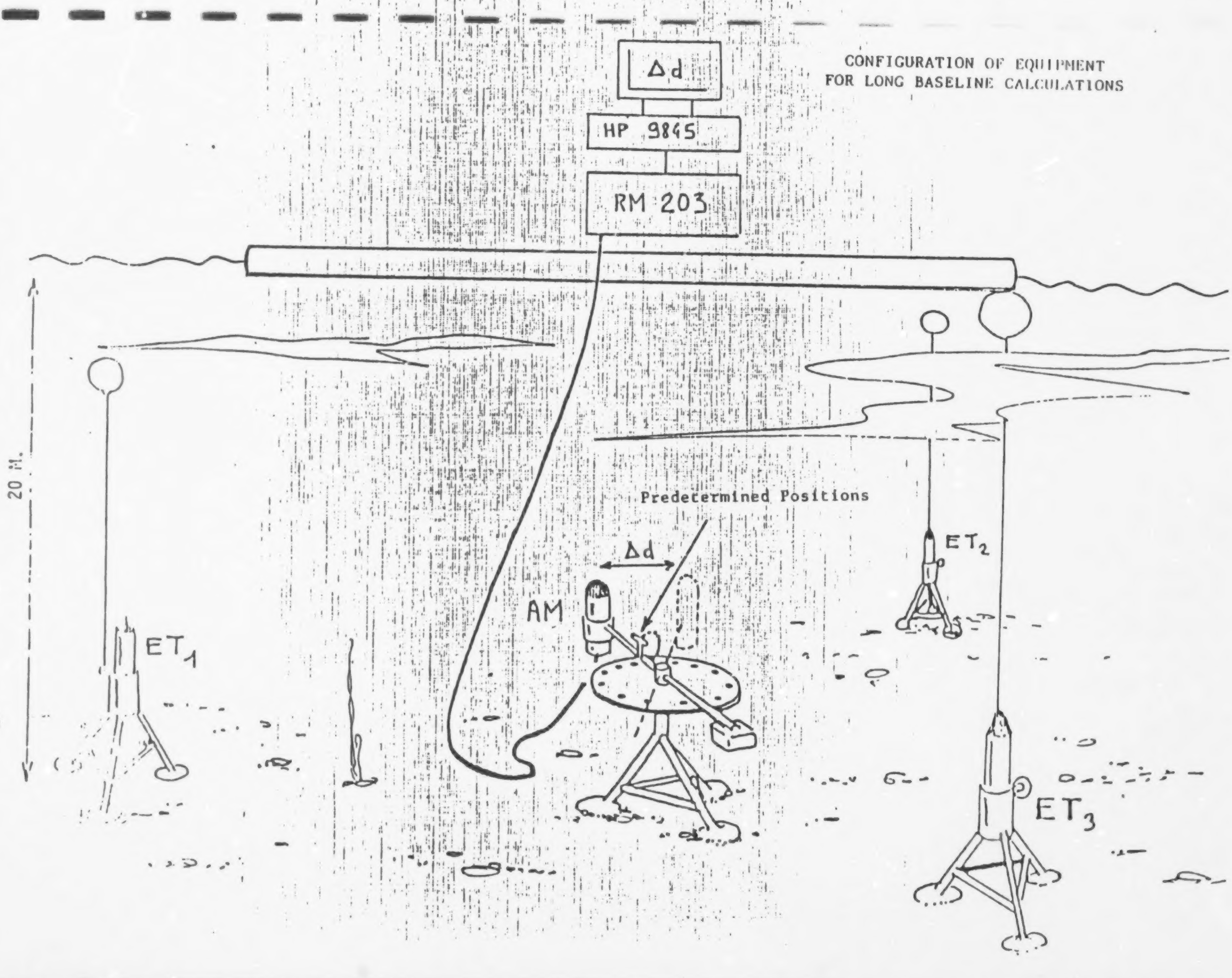
Results after 60 measurements, AM 123 fixed

Range to the transponder

102 kHz	*Standard Deviation*	*1 cm*	*Range*	*462.90 m*
57 kHz	*Standard Deviation*	*2 cm*	*Range*	*211.90 m*
87 kHz	*Standard Deviation*	*2 cm*	*Range*	*155.68 m*

See Annex 6.

CONFIGURATION OF EQUIPMENT
FOR LONG BASELINE CALCULATIONS


Δd
HP 9845
RM 203
20 M.
Predetermined Positions
Δd
AM
ET1
ET2
ET3

3.2 Resolution

The test was held to determine whether the movement of the AM 123 on the articulated arm of the special tripod could be detected at predetermined points.

The position of the arm was changed approximately every four minutes by divers. Each movement had an angular displacement of about 10 degrees.

Using the distance from the AM to the three transponders, the computer calculates the coordinates of the AM within the X,Y grid. The computer could later translate those coordinates into any other reference system for which reference points were supplied. (Geodetic.)

The repeatability of the position of the AM 123 was on the order of 2 cm. The acoustic values discarded by the computer as invalid was 1.0 to 2.0 percent.

After one complete revolution, a new acquisition, a new acquisition of the three ranges was done. The position of the AM 123 was recalculated and showed a variation 4.0 cm, with respect to its previously calculate position.

This variation was constant and could possibly be attributed to mechanical slack in the special tripod.

The ten degree angular displacements were easily visible on the graphic representation and the points outlined a circle which corresponded to the radius of the rotatable arm on the tripod.

See Annex 7,8,9.

4.0 Range Tests in Deep Water

An ET (transponder) set at 57 kHz was deployed in 900 meters of water. An AM (Acoustic Module) onboard interrogated the transponder every 4 seconds. The vessel slowly steamed away from the transponder and then returned.

Results:

Vessel Engines running; clutch disengaged.

Useable range : 1500 meters
Number of verifiable values at this range : 2 in 3

Clutch disengaged

Useable range : 1500 meters
Number of verifiable values at this range 2 in 3

See Annex 10

5.0 Conclusion

In a long baseline configuration, for a frequency in the middle of the operating range, the following results can be expected.

Repeatability : ± 1 cm at 400 meters
Resolution : ± 2 cm at 400 meters
Useable Range Shallow : 800 meters
Useable Range Deep : 1200 m

Océano
INSTRUMENTS

57 kHz

```
528   10:37:52     0.00     0.00    0.00
529   10:37:55     0.00   973.20    0.00
530   10:37:58     0.00     0.00    0.00
531   10:38:01     0.00     0.00    0.00
532   10:38:04     0.00   976.14    0.00
533   10:38:07     0.00   977.23    0.00
534   10:38:10     0.00   978.01    0.00
535   10:38:13     0.00   982.00    0.00
536   10:38:16     0.00   979.33    0.00
537   10:38:19     0.00     0.00    0.00
538   10:38:22     0.00   980.79    0.00
539   10:38:25     0.00   981.49    0.00
540   10:38:28     0.00   982.57    0.00
541   10:38:31     0.00     0.00    0.00
542   10:38:34     0.00   983.67    0.00
543   10:38:37     0.00     0.00    0.00
544   10:38:40     0.00   985.07    0.00
545   10:38:43     0.00   985.66    0.00
546   10:38:46     0.00   986.32    0.00
547   10:38:49     0.00   986.91    0.00
548   10:38:52     0.00     0.00    0.00
549   10:38:55     0.00   988.65    0.00
550   10:38:58     0.00     0.00    0.00
551   10:39:01     0.00   989.26    0.00
552   10:39:04     0.00   989.66    0.00
553   10:39:07     0.00   990.24    0.00
554   10:39:10     0.00   992.97    0.00
555   10:39:13     0.00   990.99    0.00
556   10:39:16     0.00   991.48    0.00
557   10:39:19     0.00     0.00    0.00
558   10:39:22     0.00   992.30    0.00
559   10:39:25     0.00     0.00    0.00
560   10:39:28     0.00   993.02    0.00
561   10:39:31     0.00   993.51    0.00
562   10:39:34     0.00     0.00    0.00
563   10:39:37     0.00     0.00    0.00
564   10:39:40     0.00   994.70    0.00
565   10:39:43     0.00     0.00    0.00
566   10:39:46     0.00     0.00    0.00
567   10:39:49     0.00   995.68    0.00
568   10:39:52     0.00     0.00    0.00
569   10:39:55     0.00     0.00    0.00
570   10:39:58     0.00     0.00    0.00
571   10:40:01     0.00     0.00    0.00
572   10:40:04     0.00     0.00    0.00
573   10:40:07     0.00     0.00    0.00
574   10:40:10     0.00     0.00    0.00
575   10:40:13     0.00   999.81    0.00
576   10:40:16     0.00   998.08    0.00
577   10:40:19     0.00     0.00    0.00
578   10:40:22     0.00     0.00    0.00
579   10:40:25     0.00     0.00    0.00
580   10:40:28     0.00   998.82    0.00
581   10:40:31.    0.00   999.48    0.00
582   10:40:34     0.00   999.45    0.00
583   10:40:37     0.00   999.09    0.00
584   10:40:40     0.00   999.21    0.00
585   10:40:43     0.00   999.76    0.00
586   10:40:46     0.00   999.48    0.00
587   10:40:49  1469.39   999.70    0.00
588   10:40:52   562.40     0.00    0.00
589   10:40:55     0.00   999.97    0.00
590   10:40:58     0.00  1002.01    0.00
591   10:41:01     0.00  1000.08    0.00
592   10:41:04     0.00     0.00    0.00
```

Annex 1

Range : 57 kHz

Depth : 20 meters

Oceanic
INSTRUMENTS

ANNEX 2

Range : 87 kHz

Depth : 20 meters

```
108    10:16:50   875.33     0.00     0.00
109    10:16:53     0.00   602.61     0.00
110    10:16:56     0.00   602.70     0.00
111    10:16:59     0.00     0.00     0.00
112    10:17:02     0.00   602.86     0.00
113    10:17:05     0.00     0.00     0.00
114    10:17:08     0.00     0.00     0.00
115    10:17:11   875.42   603.09     0.00
116    10:17:14   875.68     0.00     0.00
117    10:17:47   875.85   604.10     0.00
118    10:17:20   875.82   603.19     0.00
119    10:17:23     0.00     0.00     0.00
120    10:17:26   876.00     0.00     0.00
121    10:17:29   787.79   603.42     0.00
122    10:17:32   876.54   603.84     0.00
123    10:17:35   876.75     0.00     0.00
124    10:17:38   877.21   604.97     0.00
125    10:17:41   877.39     0.00     0.00
126    10:17:44   877.84   604.65     0.00
127    10:17:47   878.48     0.00     0.00
128    10:17:50   878.67   604.30     0.00
129    10:17:53     0.00   604.61     0.00
130    10:17:56   879.58   605.33     0.00
131    10:17:59   879.94   604.84     0.00
132    10:18:02   880.27   605.09     0.00
133    10:18:05   880.82   605.60     0.00
134    10:18:08   880.95   605.67     0.00
135    10:18:11     0.00   605.74     0.00
136    10:18:14   881.84   605.84     0.00
137    10:18:17   881.84   606.04     0.00
138    10:18:20   882.00   606.04     0.00
139    10:18:23   882.24   605.89     0.00
140    10:18:26   882.52   606.07     0.00
141    10:18:29   882.65   605.74     0.00
142    10:18:32     0.00   605.90     0.00
143    10:18:35     0.00   605.74     0.00
144    10:18:38   882.76   605.52     0.00
145    10:18:41   882.78   605.40     0.00
146    10:18:44   882.69   605.04     0.00
147    10:18:47   882.78   604.73     0.00
148    10:18:50   882.58   604.42     0.00
149    10:18:53   882.22   604.05     0.00
150    10:18:56   882.07   603.75     0.00
151    10:18:59   881.85   603.36     0.00
152    10:19:02   881.54   602.84     0.00
153    10:19:05   881.31   602.82     0.00
154    10:19:08   880.68   601.74     0.00
155    10:19:11   880.43   600.97     0.00
156    10:19:14   880.10   600.54     0.00
157    10:19:17   879.49   600.19     0.00
158    10:19:20   879.46   599.55     0.00
159    10:19:23   879.19   599.46     0.00
160    10:19:26   878.96   599.02     0.00
161    10:19:29     0.00   598.75     0.00
162    10:19:32   878.89   598.79     0.00
163    10:19:35   878.91   598.98     0.00
164    10:19:38   879.91   599.18     0.00
165    10:19:41   879.30   599.19     0.00
166    10:19:44   879.57   599.56     0.00
167    10:19:47   880.02   599.99     0.00
168    10:19:50   880.33   600.31     0.00
169    10:19:53   880.75   600.60     0.00
170    10:19:56   881.24   601.21     0.00
171    10:19:59   881.60   601.69   981.34
172    10:20:02   882.21   602.32     0.00
173    10:20:05   882.73   602.85     0.00
```

Océanic
INSTRUMENTS

Annex 3

Range : 102 kHz

Depth : 20 meters

```
                                                102 kHz
 976      11:20:37   665.79   422.77   827.54
 977      11:20:40   664.87   422.00   826.75
 978      11:20:43   663.75   421.10   825.91
 979      11:20:46   662.68   420.04   825.16
 980      11:20:49   661.83   419.47     0.00
 981      11:20:52   660.58   418.41   823.52
 982      11:20:55   659.89   417.87   823.05
 983      11:20:58   659.07   417.17   822.18
 984      11:21:01   658.16   416.51   821.74
 985      11:21:04   657.22   415.78   820.99
 986      11:21:07   656.54   415.02   820.40
 987      11:21:10   655.67   414.26   819.88
 988      11:21:13   654.81   413.81   819.63
 989      11:21:16   653.93   413.41   818.79
 990      11:21:19   653.49   412.98   818.37
 991      11:21:22   652.65   412.41   817.77
 992      11:21:25   651.99   411.96   817.58
 993      11:21:28   651.24   411.50   817.15
 994      11:21:31   650.42   410.92   816.76
 995      11:21:34   649.92   410.65   816.67
 996      11:21:37   649.26   409.95   816.06
 997      11:21:40   648.58   409.72   815.68
 998      11:21:43   648.01   409.57   815.56
 999      11:21:46   647.38   409.00   815.03
1000      11:21:49   646.95   408.65   814.99
1001      11:21:52   646.36   408.57   814.70
1002      11:21:55   645.75   408.21     0.00
1003      11:21:58   645.33   407.96   814.20
1004      11:22:01   644.81   407.81   814.15
1005      11:22:04   644.26   407.48   813.86
1006      11:22:07   643.89   407.34   813.88
1007      11:22:10   643.47   407.28   813.76
1008      11:22:13   642.90   406.99   813.56
1009      11:22:16   642.70   407.09   813.62
1010      11:22:19   642.19   406.84   813.60
1011      11:22:22   641.97   406.85   813.61
1012      11:22:25   642.45   406.71     0.00
1013      11:22:28   641.19   406.74   813.57
1014      11:22:31   640.78   406.65   813.58
1015      11:22:34   640.25   406.65   813.70
1016      11:22:37   640.12   406.73   813.52
1017      11:22:40   639.96   406.73   813.90
1018      11:22:43   639.46   406.74   813.93
1019      11:22:46   639.46   406.84   814.06
1020      11:22:49   638.98   406.81   814.21
1021      11:22:52   638.90   407.00   814.43
1022      11:22:55   638.67   407.06   814.50
1023      11:22:58   638.33   407.31   814.81
1024      11:23:01   638.29   407.11   814.89
1025      11:23:04   638.14   407.56   815.16
1026      11:23:07   637.95   407.76   815.40
1027      11:23:10   637.58   407.90   815.64
1028      11:23:13   637.77   408.24     0.00
1029      11:23:16   637.32   408.23   816.07
1030      11:23:19   637.42   408.71   816.58
1031      11:23:22   637.20   409.38   816.84
1032      11:23:25   637.17   409.20   817.06
1033      11:23:28   637.09   409.44   817.53
1034      11:23:31   637.09   409.79   817.83
1035      11:23:34   637.05   410.09   818.19
1036      11:23:37   636.91   410.39   818.56
1037      11:23:40   637.01   410.93   819.16
1038      11:23:43   636.96   411.23   819.44
1039      11:23:46   636.75   411.37   819.67
```

Annex 4

```
  AM-1     AM-2      AM-3      1-2       1-3      2-3
Maximum Deviation              .50
 155.67   211.89   462.90    347.25   458.72   410.18
 155.67   211.93   462.91    347.21   458.75   410.25
 155.69   211.91   462.91    347.20   458.70   410.21
 155.70   211.91   462.93    347.17   458.75     0.00
 155.67   211.92   462.90    346.84   458.72   410.30
 155.69   211.87   462.90    346.79   458.48   410.27
 155.61   211.92   462.91    347.16   458.71   410.36
 155.69   211.80   462.92    347.46   458.72   410.49
 155.67   211.92   462.90    347.22   458.76   410.25
 155.65   211.88   462.91    347.22   458.75   410.24
 155.62   211.93   462.90    347.15   458.66   410.09
 155.67   211.89   462.94    347.32   458.75   410.20
 155.70   211.92   462.92    347.23   458.71   410.17
 155.66   211.92   462.91    347.19   458.62   410.20
 134.03   211.88   462.95    347.18   458.75   410.18
 155.67   211.92   462.92    368.92   480.38   410.37
 155.68   211.92   462.91    347.19   458.76   410.23
 155.56   211.89   462.92    347.20   458.73   410.19
 155.69   211.92   462.91    346.39   458.66   410.23
 155.68   211.91   462.91    347.23   458.75   410.26
-------------------------------------------------------------------------------------
 155.67   211.90   462.91    347.18   458.71   410.25.................Average
    .03      .03      .03       .15      .07      .09.................Deviation
X : XP1=     0.00        XP2= 347.18       XP3= 234.24         234.24. Position of the RT
Y :          0.00             [illegible]        394.39         394.39  in the array
```

AUTOCALIBRATION 1
=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=

Distance between AM & Transponder #   Transponder # & Transponder #

```
   AM-1     AM-2     AM-3  |  1-2      1-3      2-3
 Ecart max :               |30.00
  155.70   211.92   462.94 |  347.24   458.78   410.23
  155.67   211.90   462.92 |  347.27   458.69   410.25
  155.55   211.82   462.93 |  346.72   458.71   410.21
  155.67   211.89   462.73 |  347.39   459.11   410.60
  155.70   211.89   462.94 |  347.41   458.84   410.24
  155.51   211.85   462.84 |  347.32     0.00   410.36
  155.67   211.88   462.90 |  347.30   458.74   410.20
  155.65   211.85   462.94 |  347.25   458.62   410.31
  155.69   211.82   462.90 |  347.24   458.74   410.24
  155.67   211.91   462.93 |  347.27   458.73   410.32
  155.69   211.94   462.91 |  347.16   458.15   410.20
  155.69   211.92   462.87 |  347.06   458.67   410.26
  155.66   211.92   462.88 |  347.18   458.74   410.28
  155.67   211.89   462.94 |  347.22   458.75   410.23
  155.34   211.90   462.94 |  347.23   458.71   410.19
  155.66   211.90   462.91 |  347.63   395.34   410.30
  155.69   211.90   462.92 |  347.29   458.67   410.24
  155.68   211.87   462.92 |  347.25   458.74   410.27
  155.70   211.90   462.93 |  347.19   458.68   410.21
  155.68   211.89   462.93 |  346.66   458.72   410.20
------------------------------------------------------------------------------
  155.65   211.89   462.91    347.22   458.71   410.27 ................ Average
     .08      .06      .06       .21      .17      .09 ................ Deviation
 X : XP1=     0.00      XP2=  347.22        XP3=  234.22       234.22.. Position of the
 Y :          0.00              0.00             -394.41      -394.41   in the array
```

Annex 5

A U T O C A L I B R A T I O N 2
=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=-=

Annex 6

Stability of the High Frequency

		87 kHz	57 kHz	102 kHz
69	17:29:48	155.68	211.92	462.90
70	17:29:51	155.69	211.90	462.90
71	17:29:54	155.67	211.90	462.89
72	17:29:57	155.69	211.89	462.88
73	17:30:00	155.69	211.89	462.90
74	17:30:03	155.69	211.89	462.91
75	17:30:06	155.68	211.90	462.90
76	17:30:09	155.67	211.90	462.90
77	17:30:12	155.72	211.91	462.90
78	17:30:15	155.68	211.90	462.91
79	17:30:18	155.67	211.89	462.91
80	17:30:21	155.68	211.91	462.93
81	17:30:24	155.67	211.89	462.89
82	17:30:27	155.68	211.90	462.90
83	17:30:30	155.70	211.89	462.90
84	17:30:33	155.68	211.91	462.90
85	17:30:36	155.69	211.91	462.90
86	17:30:39	155.69	211.90	462.90
87	17:30:42	155.69	211.90	462.90
88	17:30:45	155.69	211.89	462.87
89	17:30:48	155.67	211.91	462.89
90	17:30:51	155.69	211.90	462.87
91	17:30:54	155.66	211.89	462.90
92	17:30:57	155.69	211.89	462.90
93	17:31:00	155.66	211.90	462.90
94	17:31:03	155.69	211.90	462.90
95	17:31:06	155.69	211.90	462.90
96	17:31:09	155.70	211.89	462.89
97	17:31:12	155.66	211.89	462.90
98	17:31:15	155.70	211.89	462.89
99	17:31:18	155.68	211.89	462.90
100	17:31:21	155.69	211.90	462.88
101	17:31:24	155.69	211.90	462.90
102	17:31:27	155.67	211.90	462.90
103	17:31:30	155.68	211.90	462.88
104	17:31:33	155.69	211.91	462.88
105	17:31:36	155.70	211.90	462.90
106	17:31:39	155.66	211.90	462.90
107	17:31:42	155.70	211.89	462.88
108	17:31:45	155.71	211.89	462.88
109	17:31:48	155.68	211.90	462.89
110	17:31:51	155.68	211.90	462.90
111	17:31:54	155.68	211.90	462.90
112	17:31:57	155.68	211.90	462.88
113	17:32:00	155.70	211.90	462.90
114	17:32:03	155.68	211.89	462.91
115	17:32:06	155.68	211.90	462.90
116	17:32:09	155.69	211.91	462.90
117	17:32:12	155.61	211.92	462.92
118	17:32:15	155.68	211.89	462.89
119	17:32:18	155.70	211.92	462.90
120	17:32:21	155.66	211.89	462.89
121	17:32:24	155.69	211.89	462.89
122	17:32:27	155.68	211.89	462.90
123	17:32:30	155.66	211.89	462.90
124	17:32:33	155.61	211.92	462.90
125	17:32:36	155.67	211.89	462.90

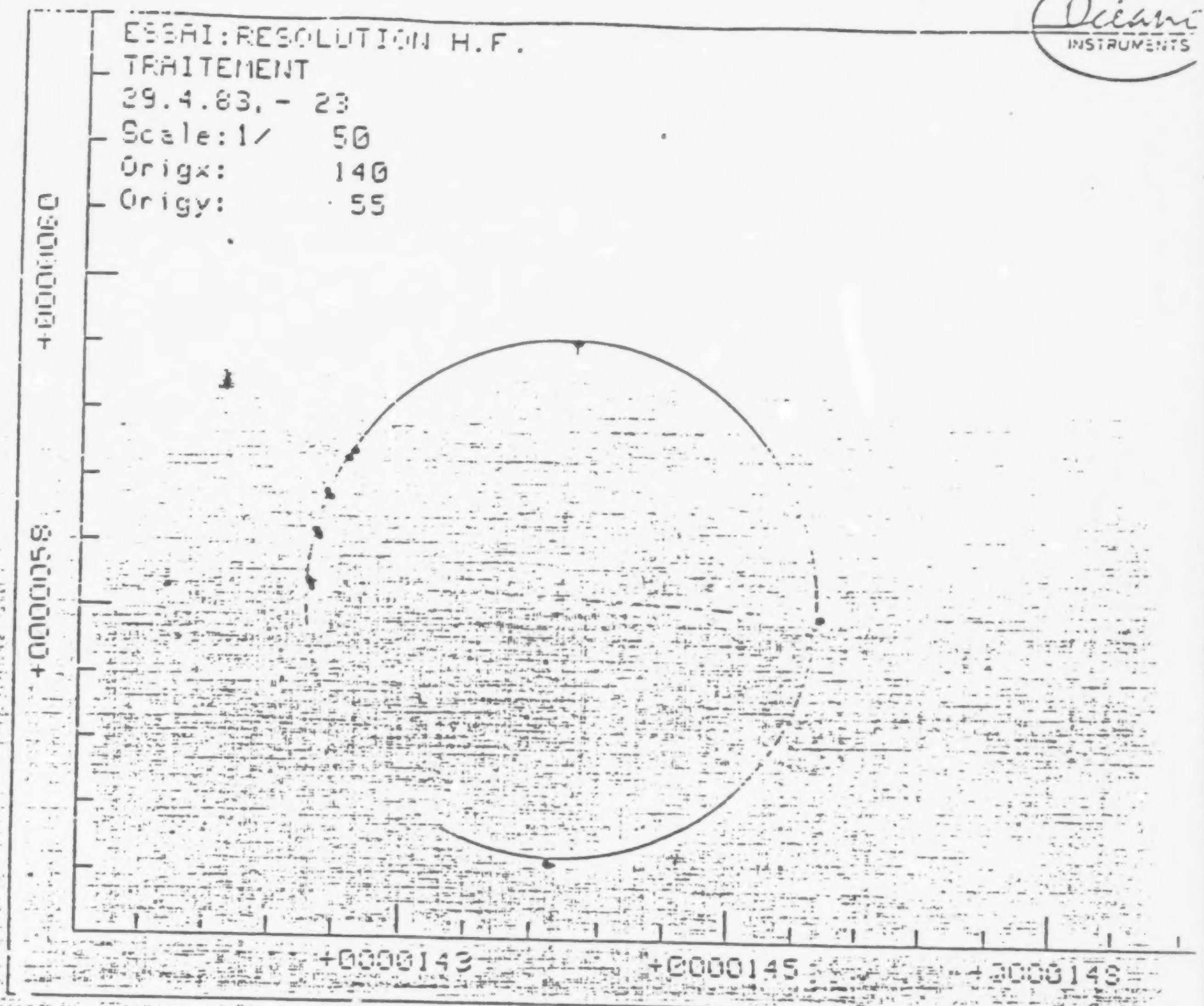
Ocean INSTRUMENTS

Annex 7

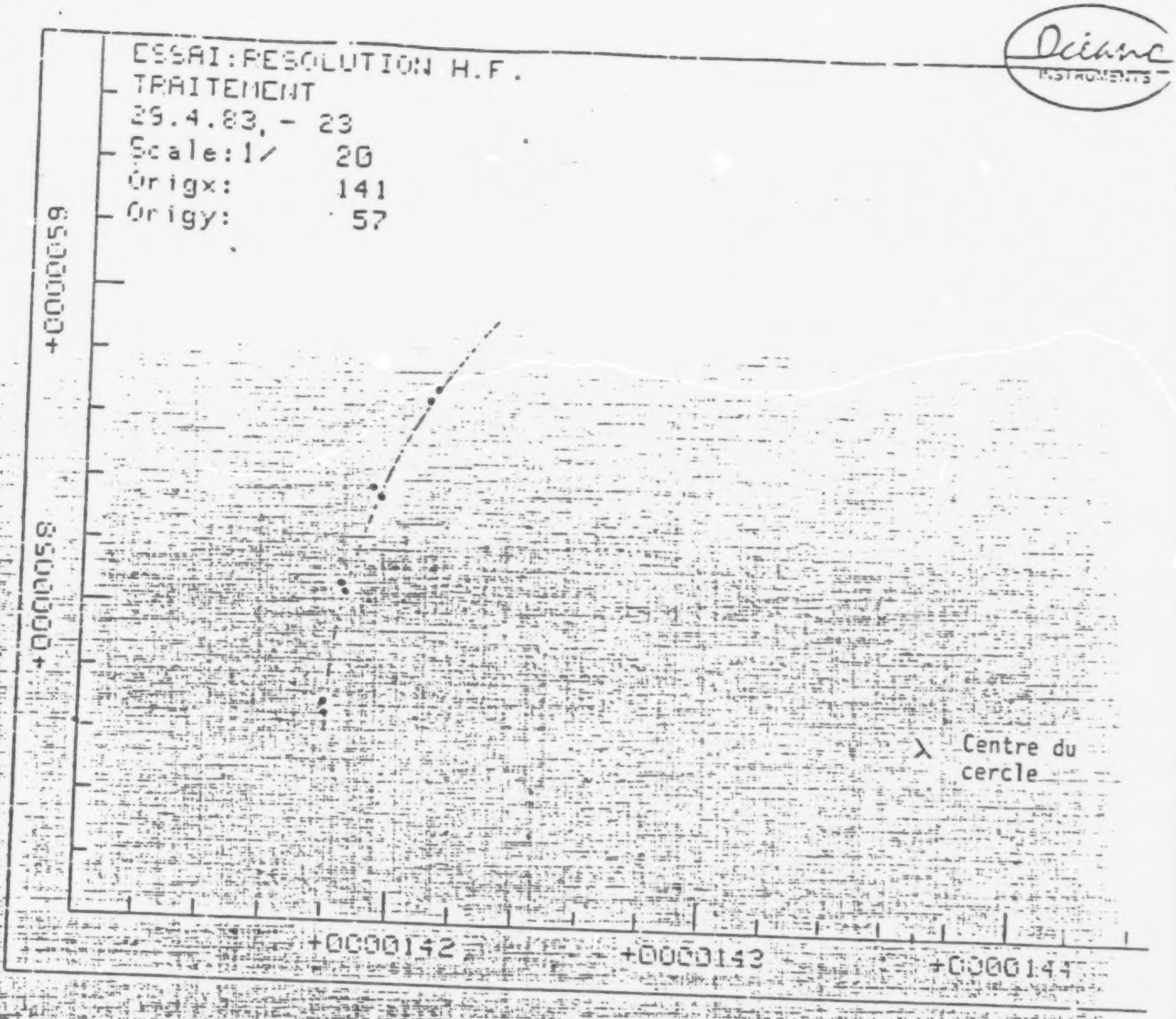
Distances

		RT 1	RT 2	RT 3	EQM	x	y	z
1191	18:28:40	153.75	213.31	462.34				
1192	18:28:40	153.71	213.34	462.38	.02	142.09	58.66	20.00
1193	18:28:40	153.74	213.32	462.34	.03	142.09	58.66	20.00
1194	18:28:40	153.75	213.31	462.34	.02	142.09	58.66	20.00
1195	18:28:40	153.73	213.32	462.34	.02	142.09	58.66	20.00
1196	18:28:40	153.76	213.31	462.35	.01	142.09	58.66	20.00
1197	18:28:40	153.70	213.31	462.34	.02	142.09	58.66	20.00
1198	18:28:40	153.73	213.34	462.35	.02	142.09	58.66	20.00
1199	18:28:40	153.73	213.32	462.36	.02	142.09	58.66	20.00
1200	18:28:40	153.75	213.31	462.34	.01	142.09	58.66	20.00
1201	18:28:40	153.76	213.32	462.36	.02	142.09	58.66	20.00
1202	18:28:40	153.75	213.32	462.33	.02	142.09	58.66	20.00
1203	18:28:40	153.69	213.32	462.34	.02	142.09	58.66	20.00
1204	18:28:40	153.75	213.32	462.37	.02	142.09	58.66	20.00
1205	18:28:40	153.72	213.32	462.35	.02	142.09	58.66	20.00
1206	18:28:40	153.75	213.33	462.34	.01	142.09	58.66	20.00
1207	18:28:40	153.74	213.32	462.36	.02	142.09	58.66	20.00
1208	18:28:40	153.74	213.33	462.36	.01	142.09	58.66	20.00
1209	18:28:40	153.72	213.31	462.33	.02	142.09	58.66	20.00
1210	18:28:40	153.74	213.31	462.34	.01	142.09	58.66	20.00
1211	18:28:40	153.75	213.32	462.33	.01	142.09	58.66	20.00
1212	18:28:40	153.68	213.31	462.32	.02	142.09	58.66	20.00
1213	18:28:40	153.77	213.31	462.33	.03	142.09	58.66	20.00
1214	18:28:40	153.75	213.33	462.35	.03	142.09	58.66	20.00
1215	18:28:40	153.72	213.34	462.32	.02	142.09	58.66	20.00
1216	18:28:40	153.75	213.31	462.35	.04	142.09	58.66	20.00
1217	18:28:40	153.72	213.31	462.34	.02	142.09	58.66	20.00
1218	18:28:40	153.72	213.31	462.34	.01	142.09	58.66	20.00
1219	18:28:40	153.74	213.31	462.34	.01	142.09	58.66	20.00
1220	18:28:40	153.72	213.31	462.34	.01	142.09	58.66	20.00
1221	18:28:40	153.77	213.33	462.32	.01	142.09	58.66	20.00
1222	18:28:40	153.76	213.31	462.34	.04	142.09	58.66	20.00
1223	18:28:40	153.75	213.33	462.36	.02	142.09	58.66	20.00
1224	18:28:40	153.75	213.31	462.35	.02	142.09	58.66	20.00
1225	18:28:40	153.75	213.33	462.34	.02	142.09	58.66	20.00
1226	18:28:40	153.73	213.33	462.36	.02	142.09	58.66	20.00
1227	18:28:40	153.73	213.31	462.34	.02	142.09	58.66	20.00
1228	18:28:40	153.75	213.31	462.35	.01	142.09	58.66	20.00
1229	18:28:40	153.74	213.32	462.36	.02	142.09	58.66	20.00
1230	18:28:40	153.66+	213.31	462.35	.01	142.09	58.66	20.00
1231	18:28:40	153.72	213.31	462.34	.04	142.09	58.66	20.00
1232	18:28:40	153.74	213.33	462.37	.01	142.09	58.66	20.00
1233	18:28:40	153.75	213.32	462.31	.02	142.09	58.66	20.00
1234	18:28:40	153.75	213.31	462.37	.03	142.09	58.66	20.00
1235	18:28:40	153.74	213.31	462.35	.02	142.09	58.66	20.00
1236	18:28:40	153.71	213.33	462.35	.01	142.09	58.66	20.00
1237	18:28:40	153.77	213.31	462.34	.02	142.09	58.66	20.00
1238	18:28:40	153.75	213.33	462.34	.03	142.09	58.66	20.00
1239	18:28:40	153.73	213.31	462.35	.02	142.09	58.66	20.00
1240	18:28:40	153.75	213.34	462.34	.01	142.09	58.66	20.00
1241	18:28:40	153.74	213.34	462.34	.03	142.09	58.66	20.00
1242	18:28:40	153.75	213.31	462.33	.02	142.09	58.66	20.00
1243	18:28:40	153.75	213.32	462.35	.02	142.09	58.66	20.00
1244	18:28:40	153.75	213.33	462.35	.02	142.09	58.66	20.00
Moyenne		153.74	213.32	462.35	.02	142.09	58.66	20.00
Ecart type		.02	.02	.02				

Océanic
INSTRUMENTS



VISUALIZATION OF THE POINTS OF MEASUREMENT ON THE MOBILE STRUCTURE IN ROTATION



ANNEX 9

VISUALIZATION OF THE DEVIATION ON THE POSITION - DISTANCE 10 METERS

THE TWO POINTS ARE THE RESULT OF TWO COMPLETE ROTATIONS OF THE ARM
(Displacement of the structure or movement of the arms supporting the AM)

Ocean
INSTRUMENTS

Annex 10

```
                       57 kHz
  407   18:31:33      1476.36
  408   18:31:37      1478.64
  409   18:31:41      1480.98
  410   18:31:45      1483.84
  411   18:31:49      1486.41
  412   18:31:53      1489.02
  413   18:31:57      1491.52
  414   18:32:01      1494.26
  415   18:32:05      1496.45
  416   18:32:09      1498.79
  417   18:32:13      1501.21
  418   18:32:17      1503.58
  419   18:32:21      1505.90
  420   18:32:25      1508.38
  421   18:32:29      1511.02
  422   18:32:33      1513.21
  423   18:32:37      1515.59
  424   18:32:41      1517.99
  425   18:32:45      1520.50
  426   18:32:49      1522.79
  427   18:32:53      1525.20
  428   18:32:57      1527.72
  429   18:33:01      1529.78
  430   18:33:05      1532.22
  431   18:33:09      1534.54
  432   18:33:13      1536.95
  433   18:33:17      1539.49
  434   18:33:21      1542.12
  435   18:33:25      1544.89
  436   18:33:29      1547.21
  437   18:33:33      1549.66
  438   18:33:37      1552.24
  439   18:33:41      1554.29
  440   18:33:45      1556.99
  441   18:33:49      1559.15
  442   18:33:53         0.00    Signal Loss Point
  443   18:33:57      1563.84
  444   18:34:01      1566.43
  445   18:34:05         0.00
  446   18:34:09      1571.43
  447   18:34:13         0.00
  448   18:34:17         0.00
  449   18:34:21      1578.91
  450   18:34:25         0.00
  451   18:34:29         0.00
  452   18:34:33         0.00
  453   18:34:37         0.00
  454   18:34:41         0.00
  455   18:34:45         0.00
  456   18:34:49         0.00
  457   18:34:53         0.00
  458   18:34:57         0.00
  459   18:35:01         0.00
  460   18:35:05         0.00
  461   18:35:09         0.00
  462   18:35:13         0.00
  463   18:35:17         0.00
  464   18:35:21      1615.36
  465   18:35:25         0.00
  466   18:35:29         0.00
  467   18:35:33         0.00
  468   18:35:37         0.00
  469   18:35:41         0.00
```

March 27, 1983

HIGH FREQUENCY SYSTEM EXCEEDS EXPECTATIONS IN MEDITERRANEAN TRIALS

Consistent acoustic measurements with a repeatability of one centimeter, coupled with short baseline system accuracies of 12 centimeters and horizontal ranges in excess of one kilometer were the results of sea trials held recently for Oceano Instruments' new High Frequency Acoustical Systems.

Adverse weather prevented the completion of all scheduled trials and forced those tests conducted to be completed in extremely shallow water. Original plans called for comprehensive performance tests in both long and short baseline configurations, from a platform off Cassis in the Mediterranean Sea, south of France. Unfortunately, force 6 weather conditions limited the program to ranging repeatability and short baseline hardware and software trials in Marseilles Harbor.

The first test was to measure the repeatability of a raw ranges from an AM 123 Acoustic Module to an ET 123 Transponder. Both the transponder and the AM 123 were mounted on fixed frames, approximately 150 meters apart in five meters of water. After ranging to the transponder on a three second cycle for 20 minutes, the results showed a consistent repeatability of one centimeter.

To check the systems' ability to detect minor changes in ranges, the Acoustic Module was mounted on a rotating head which allowed small, precise movements of 20 centimeters to be made. These movements were clearly detected by the system, again with a repeatability of one centimeter.

A short baseline array consisting of three AM 123 Acoustic Modules mounted on rigid poles was set up over the sides of the surface barge, creating a baseline of 26 X 16 meters. The Acoustic Modules were connected through a junction box to an RM 203 Rangemeter, which was connected to a Hewlett Packard 9845B computer. Pitch and roll corrections were input to the computer via an IM 100 Interface Module and an FGC VRU. Sound velocity profiles were automatically entered from data generated by a Grundy SVP connected to the IM 100. A CPS 30 pen plotter completed the system.

First the distances between each Acoustic Module were physically measured by tape. The accuracy of the measurements were then verified by acoustic mutual interrogation. As weather conditions prevented the barge from being towed out for deep water tests, the barge was manoeuvered to avoid the effects of reflection from the harbor seawall to insure the best test conditions possible.

HIGH FREQUENCY TRIALS ESTABLISH OCEANO SHORT BASELINE ABILITIES

Two ET 123 high frequency transponders were placed on the seabed a measured distance apart to test the short baseline system's accuracy. Divers measured the separation of the two frame mounted transponders at 9.4 meters, again in 5 meters of water. The barge was backed away and the system conducted a series of 65 measurement cycles, arriving at a mean separation of the two transponders of 9.52 meters with a standard deviation of 6 centimeters.

To demonstrate the very high noise immunity of the short baseline system, a powerful harbor tug with side thrusters was navigated at high power between the barge and the transponders. While air bubbles caused by the violent tug maneuvers in shallow water naturally caused some erroneous range readings due to the change in the sound velocity profile, the high frequency system was otherwise completely unaffected by ship induced noise. The RM 203 Rangemeter with its sophisticated receiver filters was able to pick up transponder replies without interruption.

The final portion of the tests demonstrated how the Oceano high frequency system can track a moving subsea vehicle. To do this an ET 123 transponder was suspended approximately one meter below a vessel which moved about the harbor. The short baseline system was used to track the vessel continuously, while plotting its position in real time on both the computer CRT and plotter.

The sea trials were witnessed by representatives of several companies including C.N.E.X.O, Electricite De France, Comex, British Oceanics, Travocean, SPIE Offshore, ACB and SAS.

APPLICATION OF THE MICRONAV ACOUSTIC TELEMETERING INSTRUMENTATION SYSTEM DURING THE INSTALLATION, LEVELLING, PILING AND DIMENSIONAL CHECKING OF THE HUTTON TLP TEMPLATES

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Sonardyne Limited

G J White
Conoco (UK) Limited

1 INTRODUCTION

Conoco (UK) Ltd is the operator for the Hutton Field in Block 211/28 in the UK sector of the North Sea. The field has a water depth of approximately 148 metres and is being developed with the World's first commercial application of a Tension Leg Platform (TLP). This novel design concept promises a more economical method of exploiting deep-water oil fields. However, it poses new challenges in sub-sea engineering which can be evaluated in the comparatively shallow waters of the North Sea. The Hutton TLP design incorporates a 32-slot Well Template and four Foundation Templates deployed on the seabed, and a Floating Platform which is held under tension by tethers connected to the Foundation Templates "Fig. 1". The Well Template was installed in May 1981 and the four Foundation Templates in April 1983. The Floating Platform is scheduled for installation during 1984.

Correct and efficient installation of the Hutton Templates required the use of precision underwater measurement equipment, controlled entirely by cable-less acoustic telemetry transmission. Conoco (UK) Ltd contracted Sonardyne Ltd to develop special instrumentation to meet these requirements. This resulted in MicroNav, an underwater autonomous instrumentation system based on extensive use of acoustics for precise distance measurement and cable-less telemetry of data. The system was first used during the installation of the Well Template (Ref. 1) and then for the installation, levelling, piling and "as laid" dimensional checking of the Foundation Templates. This paper discusses the work carried out during the later phases.

2 INSTALLATION METHOD

The four Foundation Templates lie at the corners of a 78 x 74 metre rectangle whose centre is 22.5 metres offset from the centre of the Well Template "Fig. 2". Each Foundation Template weighs 1000 tons and measures 15 metres square by 8.5 metres high, "Fig. 3", and is supported on four mud mats whose heights could be adjusted for levelling the Templates. The Templates are each retained by eight main 67 x 1.8-metre tension piles and one 30 x 1.8-metre pin pile.

All the Templates, including the Well Template in 1981, were deployed using a semi-submersible crane vessel (SSCV). A Guidance Frame, "Fig. 4", was used to meet the high installation position tolerances required (see Section 3). This comprised an accurately dimensioned rigid frame, 91 x 48 x 7.5 metres high. The required relative positions of two Locating Pins on each Foundation Template were precisely defined on the guidance Frame by four sets of Template Positioning Buckets. The position of the Guidance Frame itself was defined by two Bumper Pile Location Buckets which mated with two pre-installed Bumper Piles whose positions had been accurately established relative to the Well Template.

APPLICATION OF THE MICRONAV ACOUSTIC TELEMETERING INSTRUMENTATION SYSTEM DURING THE INSTALLATION, LEVELLING, PILING AND DIMENSIONAL CHECKING OF THE HUTTON TLP TEMPLATES

The installation sequence was as follows:

a) Install the Guidance Frame in the required position relative to the Well Template.
b) Adjust mud mats as necessary to level the Guidance Frame
c) Install all four Foundation Templates in their required positions relative to the Guidance Frame
d) Drive Foundation Template Pin Piles
e) Adjust Foundation Template mud mats as necessary for levelling
f) Stab main piles into Foundation Templates (8 per Template)
g) Drive main piles
h) Grout piles
i) Remove the Guidance Frame.

3 POSITION MONITORING SYSTEM REQUIREMENTS

3.1 Operational Requirements

3.1.1 Guidance Frame Installation: The operational requirements of the installation position monitoring system, MicroNav, were:

- Provide primary guidance information to Conoco's installation contractor during the deployment of the Guidance Frame to permit safe engagement with two Bumper Piles positioned adjacent to the Well Template.

- Check critical dimensions on the Guidance Frame after engagement with the Bumper Piles to ensure there was no distortion, damage or mis-positioning between the Guidance Frame and Well Template.

- Check levelness and relative heights of the Guidance Frame adjacent to four mud mats as a pre-requisite to any jacking operations.

3.1.2 Foundation Template Installation: The requirements in this case were:

- Provide primary guidance information during the deployment of each Foundation Template to permit safe engagement of the Template Locating Pins with the Positioning Buckets on the Guidance Frame.

- Monitor the levelness of each Foundation Template after deployment as a pre-requisite to any jacking operations, and thereafter when each pile had been driven. Determine final Template attitudes after grouting.

- Determine the relative heights of each Foundation Template with respect to each other and in relation to the Well Template. initially as a pre-requisite to any jacking requirements, and finally after piling/grouting operations.

- Determine the final relative positions of each Foundation Template with respect to each other, and in relation to the Well Template.

3.2 Position Tolerances, "Fig. 2"

The tolerances for the final positions, orientation and levelness of the four Foundation Templates had been specified by Conoco following hydrodynamic analysis of the TLP:

3.2.1 Position:

- The position of each Foundation Template centre to be within a radius of 500mm of the Target Centre specified in relation to the Well Template.
- The distance between the centres of adjacent Foundation Templates to be within 500 mm of the specified value.
- The difference in distance between the centres of opposite pairs of Foundation Templates not to exceed 500 mm.
- The square root of the sum of the squares of the difference in distances between the centres of opposite pairs of Foundations not to exceed 500 mm.

These tolerances imply that with the position vectors evenly distributed between the four template positions, and in the most unfavourable geometric arrangement, the maximum allowable magnitude of the position error vector is 120mm. A further requirement was that the maximum errors in the position measurement (instrumental and environmental) should not exceed one third of the required tolerance. The most severe interpretation of this requirement dictated an absolute accuracy of ±40mm.

3.2.2 Orientation:

- The orientation of each Foundation Template to be within ±2 degrees of the specified orientation related to the Well Template.

To meet the "one third" maximum error dictated a measurement accuracy within ±0.7 degree.

3.2.3 Levelness:

- Each Foundation Template to be installed to a tolerance of ±0.5 degrees to the horizontal.

To meet the "one third" maximum total allowable error, a measurement accuracy within ±0.2 degrees was required.

3.2.4 Relative Heights:

- The relative heights of each Foundation Template with respect to the Well Templates had to be determined to the highest possible precision.

The tolerance which could be achieved in practice was determined as ±50 mm.

3.3 Data Transmission

To circumvent the operational and logistic problems associated with umbilical cables, the primary data transmission between each Template MicroNav and the surface computing/display equipment was required to be an acoustic telemetry link. In addition, to permit risk-free manoeuvring during deployment and engagement operations, a maximum position data uprate interval of 10 seconds was required.

3.4 Shock and Vibration Loading

The units installed on the Foundation Templates had to be designed to withstand the vibration and shock loading associated with piling. In the absence of an exact operational specification the following representative criteria were agreed:

Shock loading	200g
Vibration loading:	1 to 27 Hz at 0.56 mm constant peak displacement 27 to 52 Hz at 0.096 m/sec constant peak velocity 52 Hz to 100 Hz at 3 g constant peak acceleration.

4 MICRONAV SYSTEM DESCRIPTION

The MicroNav underwater instrumentation system was developed from components of Sonardyne's PAN (Programmable Acoustic Navigator) and Compatt (Computing and Telemetering Transponder - Ref. 2). It comprises a microprocessor-based Control and Telemetry Unit, CTU, "Fig. 5", with internal sensors for monitoring roll, pitch, depth and water temperature, and a variety of external sensors.

4.1 Internal Sensors:

The Schaevitz pitch and roll sensors have a claimed measurement accuracy within 0.02% over a range of ±14.5 degrees. Two depth-sensor options are available, a strain gauge with an accuracy of 0.3% or a Paroscientific Digiquartz sensor which has a claimed measurement accuracy of 0.025%. A calibrated platinum-resistance thermometer determines the water temperature to within 0.1 degrees Centigrade. The CTU is isolated from shock and vibration loading by a damped sprung suspension frame, "Fig. 5", and is connected to the external sensors using underwater-pluggable connectors.

4.2 External Sensors

The primary external sensors are four combined Transponder Remote Transducers, TRTs, "Fig. 6", which are positioned at convenient known points on a structure to form a Short-Baseline (SBL) acoustic positioning system. Any TRT may be selected as the master interrogator under software control, the replies being received in all four transducers. By measuring distances precisely between standard transponders (or an array of MicroNav TRTs) on a fixed seabed structure, such as the Well Template, and TRTs on the structure being deployed, a 3-dimensional picture of the relative position can be accurately computed. Facilities exist in each MicroNav for remote self test and calibration of each TRT under software control, as well as selection of wide-band or narrow-band measurement modes. Any of the TRTs may be remotely switched into a transponder mode to provide ranging from other MicroNavs or related acoustic positioning systems.

Other external sensors include an Altimeter, "Fig. 7", to acoustically measure height above sea bottom, and a North-seeking Gyro compass with its associated Battery Pack, "Fig. 8".

4.3 Communication Links:

Communication between the surface acoustic tranceiver PAN and MicroNav is by a secure acoustic command/telemetry link. The primary acoustic link (ACL) transducer is incorporated in each CTU, but a remote ACC transducer is available should masking pose a problem, "Fig 6". A fully duplex modem umbilical link is also available via an Umbilical Control Unit. This is used for testing above water.

4.4 Power Supply

With the exception of the Gyro, power supply for a MicroNav system is supplied from an internal lithium sulphur dioxide battery pack in each CTU.

5 MICRONAV SYSTEM DEVELOPMENT

Following the installation of the Well Template in 1981 (Ref. 1), further development and extensive field trials of MicroNav continued to prepare for the more complex Foundation Template installation phase.

5.1 Measurement Accuracy

The main factors affecting the measurement and position accuracy which can be achieved in practice with underwater acoustics are:

a) Uncertainties in sound velocity measurement.
b) Resolution and accuracy of the electronic time measurement.
c) Resolution and repeatability of the acoustic pulse detection.
d) Relative geometry between transducers and transponders.

With modern microprocessor-based equipment, such as PAN and MicroNav, the timing aspect does not limit the system performance and will not be considered further in this paper. The sound velocity uncertainty is range dependent and in standard homogeneous sea water is considered to contribute an error of 0.03% of range. Its value is either determined using a calibrated velocimeter, or computed from measurements of the water temperature, salinity and pressure.

The resolution of the acoustic pulse detection is, therefore, the factor which constitutes the greatest limitation to accuracy over short ranges, and depends on the frequency and type of signal processing used. Sonardyne supply equipment operating in either Medium Frequency (MF) or High Frequency (HF) bands when high position accuracies are required. For the purpose of this paper, the operational band centre frequencies are taken as 25 kHz for MF and 50 kHz for HF.

Wideband signal processing is more accurate than narrowband processing, but is more prone to noise interference. Narrowband processing can be almost as stable as wideband processing, but is more prone to long-term drift since temperature and ageing can affect the centre frequency of the filters.

Comparative theoretical accuracies for the acoustic pulse detection resolution of equipment operating in the MF or HF bands can be summarised as follows:

Processsing Technique	Detection Resolution	
	MF	HF
Narrow Band (Long Term)	± 120 mm	± 60 mm
Narrow Band (Calibrated)	± 60 mm	± 30 mm
Wide Band	± 30 mm	± 10 mm

It was considered that Conoco's linear measurement accuracy specification of ± 40 mm could theoretically be met using a wide band MF system. This was proved in practice during two sets of MicroNav trials in Plymouth Sound with TRTs deployed on four concrete blocks set up as an 80-metre array to represent the four Foundation Templates. The array dimensions were checked absolutely using a taut wire. An equally important aspect of the trials was to assess the random positioning errors which occur under operational conditions with an array of TRTs. This represented the worst case test, since considerably greater measurement redundancy existed in the real case.

5.2 Level Measurement

The attitude (pitch and roll) of each Template was required within ± 0.2 degrees. Each MicroNav CTU was suspended in an external shock and vibration frame which was then bolted onto mounting tables on each Template, "Fig. 5". This introduced unknown offsets to the attitude sensor readings. It follows that each sensor had to be calibrated relative to a defined reference plane on each Template prior to deployment.

This posed a logistic problem since the Templates were fabricated in Japan. The solution adopted was to install Calibration Reference Plates on each Template in Japan. With each Template jacked into the correct horizontal position, as defined by the verticality of the pile sleeves, the Calibration Plates pitch and roll angles were determined using a dual axis inclinometer "Fig. 9". When the Templates arrived at the Moray Firth Services Co. base in Invergordon, the MicroNavs were installed (two per Template), and the attitude sensors calibrated against further readings taken simultaneously on the Calibration Reference Plates. The calibration was considered to be accurate to within ± 0.1 degrees.

5.3 Relative Height Measurements

Relative height measurements of each Template within 50 mm in a water depth of 150 metres had been stated as a target. This implies a measurement accuracy within 0.017% using a 300 psia pressure transducer. A Paroscientific Digiquartz sensor (Ref. 3) was selected, but because the pressure signals which had to be measured were so small compared with the total pressure, it was necessary to determine the voltage and temperature sensitivity, and drift of the sensors. These sensors are also sensitive to shock which mainly effects the zero offset, with the span, resolution and linearity being little affected.

Research showed that long-term drift (Ref. 4) and shock were the main source of errors, even though the sensors were triple anti-shock mounted in their MicroNav shock frames.

5.3.1 Long Term Drift: Sets of aged sensors for the 4 Guidance Frame MicroNavs, and for one MicroNav on each Foundation Template, were matched using a least squares process with all the sensors at the same height and subject to a similar bottom pressure to that expected at Hutton for a period of at least 24 hours.

5.3.2 Shock Effects: To avoid possible shock-induced damage to the pressure sensors, it was decided to only incorporate precision sensors in one of each pair of Foundation Template MicroNavs. These MicroNavs would be removed by divers after the initial deployment and any jacking operations, but before piling commenced. They would then be redeployed to determine the "as piled" relative heights.

It was considered that with these precautions, the relative pressure measurements could be determined over a limited range to within 3 millibar. In standard homogenous sea water, this represents approximately 30 mm. However, these measurements then had to be related to the Template reference plane using various linear and angular offsets. This contributed to a total error budget within 50 mm.

5.4 Data Rate

An acoustic telemetry link was required together with a data update period within 10 seconds. This necessitated a data rate of 100 Baud. Successful operational trials were carried out in 150-metre water in Loch Linnhe in 1982 with a prototype MicroNav to prove the telemetry link, and the computation algorithms. Further simulated deployment trials using two MicroNavs, representing the Well Template and a Foundation Template, were subsequently carried out in Sonardyne's test tank. This checked the complete system including the acoustic control/telemetry link, acoustic distance measurement accuracy, all the sensors, the computation/display algorithms and the software operation.

5.5 Vibration and Shock Tests

Vibration and shock tests were carried out of MicroNav units (CTU and a TRT) in their respective isolation mounts at the National Gas Turbine Establishment (NGTE), West Drayton.

5.5.1 Vibration Tests: A resonance search was carried out with the equipment mounted on both horizontal and vertical vibration tables. These tests were carried out from 1 to 100 Hz and any resonances noted and the amplification measured. The amplification or "Q" did not exceed 3 for any mode of resonance. A swept endurance test was conducted for 1 hour minimum with the equipment subjected to the following vibration loading:

1 to 27 Hz :	0.56 mm constant peak displacement
27 to 52 Hz :	0.096 m/sec constant peak velocity
52 to 100 Hz :	3g constant peak acceleration

The equipment continued to operate correctly throughout these tests.

5.5.2: Shock Tests: These were carried out using the Two Tonne Shock Machine. The test units were bolted onto the machine table and the shock level gradually increased to:

- Ramp up 200g for 3 milliseconds
- Ramp down 100g for 6 milliseconds.

The NGTE machine is designed to replicate conditions on the deck of a warship hit by a shell or depth charge, and peak accelerations on parts of the table can exceed 1000g for short periods. Five shock tests were completed, and the maximum response recorded inside the MicroNav isolation mount was 25 g for peak input of 1000g. All equipment functions were checked after each test and remained within specification. In particular, the attitude sensor readings did not vary by more than ± 2 minutes of arc throughout the tests.

6 MICRONAV SYSTEM APPLICATION DURING THE HUTTON TLP PROJECT

6.1 Primary Positioning - Well Template Installation

Primary positioning describes installation of a single structure or first of a group of structures on the seabed, such as the Well Template, and has been described in detail by White (Ref. 1). MicroNav was used in an inverted SBL mode to position the Well Template relative to a SSCV without the use of a seabed transponder array, and without the use of any permanently-installed acoustic equipment on the SSCV. The TRTs on the Well Template were directed upwards to a range to a single transponder attached as a temporary reference marker below the hull of the SSCV. True orientation was determined by the MicroNav Gyro compass option.

6.2 Secondary Positioning - Foundation Template Installation

This positioning mode refers to the installation of further structures, such as the Guidance Frame and Foundation Templates, relative to an existing seabed structure, such as the Well Template, where positioning tolerances are more stringent than for Primary Positioning. The following sections discuss different aspects of the Hutton installation.

6.2.1 Data Format, Computation and Display: MicroNav systems installed on the structure being deployed were connected to 4 TRTs positioned as far as possible to give clear line of sight to transponders located at the four corners of the Well Template, "Fig. 10". By virtue of redundant ranges measured between the multiple transducers and transponders on the two structures, together with measurements from the attitude, depth and altitude sensors on the lowered structure, a 3-dimensional computation determined the relative position and critical offset parameters. These computations were carried out using a Hewlett Packard 9845B desk top computer, "Fig. 11", and the relative plan position and height of each structure presented as a video display or on hard copy for use by the SSCV Superintendent.

The following data format was adopted to achieve the fast update required for risk free operations:

a) Command Initiation of a Measurement Cycle.
b) Measure four complete sets of ranges from the TRTs to the Well Template transponders.
c) Measure the pitch, roll, height and depth of the lowered structure.

Computation and display of the relative position occurred after each set of measurements. During the early deployment stage, the height was derived from the mean of the 3-dimensional acoustic computation and the depth information. Once altitude data was acquired (within 50 metres of the seabed) the computed height was weighted in its favour. Typical displays obtained during deployment of the Guidance Frame and a Foundation Template are shown in "Fig. 12" and "Fig. 13".

6.2.2 Acoustic Telemetry Link: The MicroNavs were controlled acoustically throughout the operation via PAN without any direct umbilical cable connection, returning the position data to the HP9845 by acoustic telemetry. The position update rates achieved in practice were:

a) Three positions based on acoustic ranges and previous altitude, depth and attitude data - every 8 seconds.
b) Fourth position based on acoustic ranges and new altitude, depth and attitude information 12 seconds.

Data corruption throughout the installation was negligible with long periods of error-free data. The only significant corruption occurred with one Foundation Template where the direct and remote ACL transducers were both intermittently masked from the PAN dunking transducers during the early deployment stage by the Template spreader frame. This occurred because in selecting the suitable locations for the remote ACL transducers, it had not been appreciated that the four Templates would not necessarily be deployed in the same relative orientation with respect to the SSCV. This minor drawback disappeared as the Template was lowered deeper, and was overcome completely with the second 'errant' Template by jury rigging the remote ACL transducers on the opposite side of the Template, thus reducing the risk of interference from the spreader frame.

6.2.3 Range Masking: Masking of acoustic ranges to some Well Template transponders occurred during the early deployment phase of two Foundation Templates. This arose due to the use of directional TRT transducers (chosen to meet the final dimensional tolerances), and because operational constraints required two Templates to be deployed almost straight down, without sufficient lateral displacement to ensure line-of-dight at the surface to the Well Template transponders. The solution adopted was to deploy each Template to a depth of 50 metres below the SSCV before determining its relative position!

6.2.4 Final Docking: Final engagement of the Guidance Frame and Foundation Templates was only carried out following visual confirmation using ROVs. However, since the MicroNav systems provided continuous "real time" information of the movement of each structure, this played an important part in the docking operations, as well as significantly reducing the installation times involved using ROVs alone.

6.3 Attitude Levelness

The MicroNav attitude sensors detect tilt of only one minute of arc even though isolated in an anti-shock/vibration frame. These sensors were used initially to determine if any of the Templates had to be levelled, and then to monitor jacking operations. Ten sets of measurements were taken on each occasion, the mean pitch and roll of each Template derived, and the relative height difference between each jacking point computed. "Fig. 14" shows the results for Template F4 before and after jacking.

The attitude of each Foundation Template was also monitored after each pile was stabbed and driven to check that it was still within level tolerance, and finally after all the piles had been grouted.

6.4 Relative Heights

Accurate relative height information was determined from the calibrated MicroNav Digiquartz sensors during the Guidance Frame deployment to ensure the Frame was level on the seafloor, and to monitor the effects of jacking. In the case of the Foundation Templates, their heights relative to each other and relative to a defined reference on the Well Template were required, in order to compute the exact length of the TLP tethers. This was achieved using calibrated Digiquartz pressure sensors incorporated in the Foundation Template MicroNavs, and in a Real Time Compatt Tide Gauge. This was installed as a reference sensor at a defined location on the Well Template whose height had been established by the Institute of Oceanographic Sciences relative to LAT.

The final "as-piled" relative heights between the centres of each Foundation Template and the reference datum on the Well Template, were determined on three separate occasions by direct comparison between the absolute pressures recorded at the Compatt Tide Gauge on the Well Template, and the MicroNav pressure sensors on each Foundation Template. These measurements were taken during calm conditions and at slack water to minimise wave and tidal affects. Identical sequences of measurement were recorded on each occasion. In each sequence the mean Tide Gauge reading was calculated to eliminate any tidal variation, and the pressure differences computed between each MicroNav. These were then converted to height differences in millimetres using constants determined during the calibration checks, and a water density established from salinity measurements and the MicroNav temperature measurements.

6.5 Post Template Deployment Position Monitoring

The MicroNavs installed on the Guidance Frame were used in "inverted SBL" modes to determine the 3-dimensional positions of standard transponders mounted variously on the SSCV, main piles, the Menck underwater hammer power pack, "Fig. 15", diving bell or any other object which had to be accurately positioned relative to the Foundation Templates. This application significantly decreased the time required to stab the piles and hammer, and clearly demonstrated the major advantages which accrue from use of a seabed positioning system functioning independently of surface navigation aids. The plan position and height of each object was presented on the VDU display, "Fig. 16", and used to direct movement of the SSCV crane, or adjust the anchor winches to achieve exact positioning on the seabed (relative heights and positions within ± 250 mm).

Care had to be exercised to select the optimum MicroNav and correct TRT as the master interrogator to avoid masking, particularly as the number of stabbed piles increased (each projecting 68 metres above the seabed). It was however significant that the acoustic telemetry was generally unaffected by multipath signals associated with the piles.

6.6 Final Dimensional Checking

6.6.1 Guidance Frame: The four Guidance Frame MicroNavs with their multiple transducers were used to make dimensional checks between known points on the Guidance Frame with great rapidity, telemetering the information to the SSCV. Typical values given in "Table 1" are means of sets of wideband reading observed in each direction, each set comprising more than 10 individual range measurements. The standard deviations for each mesurement set are less than 10 mm. The water temperature was recorded at the start and end of the measurements, and the mean value used to compute the velocity of acoustic propagation from Medwin's equation. The salinity in each case was based on water samples obtained by divers at the same level as the TRTs (approximately 7 metres above the seabed).

The expected linear measurement accuracy of each MicroNav range measurement between TRTs operating in the medium frequency band in a wide band mode had been shown to be within ± 40 mm (see Section 5.1). The tabulated errors are the difference between the "as-built" engineering measurements, established using standard surveying techniques to better than ± 5mm, and the acoustic measurements. All the results are within the claimed measurement accuracy, which confirms that no distortion or damage had occurred during deployment of the Guidance Frame.

Measurement checks were also taken to the Well Template transponders to ensure there was no mis-positioning between the Guidance Frame and Well Template. During these checks it was established that some range measurements were masked by mounds of drilling debris deposited on the seabed around the Well Template. This could have caused serious problems during the final dimensional checks of the Foundation Templates. The two southerly Well Template transponders were thus relocated by divers from corner positions to the top of the transducer guide poles used for the Well Template installation (Ref. 2).

6.6.2 Foundation Templates: The "as-laid" dimensional survey was based on a total of 37 measured acoustic ranges. Nineteen ranges were measured between the Foundation Template TRTs, and 18 ranges used to fix the Foundation Templates relative to the Well Template. All the measurements were taken after piling operations had ceased, and in some cases after removal of the Guidance Frame.

The recorded observed values between the Foundation Templates TRTs "Table 2" are means of sets of wideband acoustic readings taken in each direction, each set consisting of more than 10 individual range measurements. In all cases the standard deviations were within 10 mm. The acoustic velocity was computed from temperature and salinity measurements, and each measurement is considered accurate to within ± 40 mm.

The tabulated differences are between the theoretical dimensions, assuming perfect deployment, and the observed acoustic dimension. With the exception of one diagonal between Template F1 and F4 (rejected during the final adjustment), the differences are within ± 60 mm, which is within the expected tolerances of the Guidance Frame. This proves that no distortion or mispositioning had occurred during the installation of the Foundation Templates.

The measurements taken to the Well Template are means of sets of acoustic readings taken in mixed narrow and wideband modes between the Foundation Template TRTs and the Well Template transponders on the Well Template. Measurements taken across the Well Template Structure were ignored due to risk of multipath interference. Each measurement is considered to be accurate to within ± 200 mm. This is substantiated by comparison with the theoretical dimensions, assuming perfect deployment "Table 3". The only exceptions are two measurements to transponder 7. These were considered grossly in error due to drilling debris North of the Well Template masking the direct signal path, and were rejected in the final adjustment.

7 FINAL "AS LAID" RESULTS

These are summarised under four headings:

7.1 Final Positions

7.1.1 Adjustment: The dimensions measured between each Foundation Template and to the Well Template "Table 2 and 3" were used in a least squares adjustment programme to compute the final "as laid" positions of the Foundation Templates relative to the Well Template. Any measurement was rejected where the residual exceeded the claimed measurement accuracy of the system (± 40 mm Foundation to Foundation Template, and ± 200 mm to the Well Template.)

The adjustment weights the wideband measurements more heavily than the mixed narrowband/wideband measurements on the basis of accuracy trials carried out earlier on both types of signal processing. The adjustment is thus more accurate for relative measurements than for the absolute positions of the various components. This is reflected in the accuracy figures listed below. The adjustment residuals, observed minus adjusted values, were within ± 20 mm for the measurements taken between the Foundation Templates and ± 80 mm for the measurements taken to the Well Template.

The distance between the centres of the two diagonals between opposite the Foundation Templates is considered to be free of sound veloicty errors because of its central position, and is the most accurate (and critical) result.

7.1.2 Final Tolerances: The adjustment computes the various tolerance factors specified by Conoco. The final tolerances are:

- "The position of each Foundation Template centre shall be within a radius of 500 mm of the Target Centre, defined relative to the Well Template":

  Template F1 = 160mm ±130 mm
  F2 = 150mm ±110 mm
  F3 = 120mm ±70 mm
  F4 = 40 mm ±60 mm

- "The distances between the centres of adjacent Foundations shall be within ±500 mm of the specified value":

  F1 - F2 (B) = + 50mm ±40mm
  F2 - F4 (C) = - 00mm ±40mm
  F4 - F3 (D) = + 40mm ±40mm
  F3 - F1 (A) = + 20mm ±40mm

  Note - +ve sign denotes actual distance is longer than specified

- "The differences in distance between the centre of opposite pairs of Foundations shall not be greater than ±500mm"

  A - C = +20mm ±40mm
  B - D = +10mm ±40mm

- "The square root of the sum of the squares of the difference in distance between the centre of the opposite pairs of Foundations shall not be greater than 500mm"

  $((A - C)^2 + (B - D)^2)^{1/2}$ = ±30 mm ±40mm

The observed values are all within Conoco's specified tolerances. The critical distance between the centres of the two lines joining the centres of diagonally opposed Foundations computes as:

14mm ±33mm (95% CERTAINTY)
±50mm (99.7% CERTAINTY)

7.2 Orientation

Calculations based on the final adjusted positions of the four Foundation Templates show that orientation of each Template is within the ± 2 degrees tolerance specified by Conoco.

The relative bearings are listed below. A +ve sign indicates anti-clockwise rotation, a -ve sign indicates clockwise rotation.

Template	Rotation (deg)	
1	-0.19	±0.15°
2	-0.15	±0.15°
3	-0.22	±0.15°
4	-0.07	±0.15°

7.3 Levelness

7.3.1 Field Measurements: The final attitude values were taken as the mean of the measurements obtained with two MicroNavs on each Template:

Template	Pitch(°)	Roll(°)
F1	-0.02	+0.03
F2	+0.21	-0.01
F3	-0.13	-0.04
F4	+0.24	+0.09

The readings were obtained after piling and grouting operations had ceased, and were derived from sets of more than ten individual measurements of each attitude sensor. The deviation of each data set was within ±0.01°. It is of interest that comparison between measurements taken before and after piling operations showed a maximum change of level of 0.1°.

7.3.2 Measurement Accuracy: The measurement accuracy is made up as follows:

a) Sensor measurement in resolution - within 0.004°.
b) Calibration Errors in Japan - 0.05°.
c) Calibration Errors in Invergordon - 0.05°
d) Hysteresis of MicroNav Shock Frame - 0.03°

- giving a total error budget of 0.13°. It follows that each Foundation template is level to within the required ±0.5° tolerance.

7.4 Relative Heights

7.4.1 Field Measurements: The relative heights between the centres of each Foundation Template at top flange elevation and the IOS tide gauge reference datum on the Well Template were determined by direct comparison between absolute pressure measurements. The pressure differences between the Well Template Compatt Tide Gauge and each Foundation Template MicroNav sensor were corrected to height differences in millimetres using a water density (0.4454 psi per foot) computed from salinity (35.26%) and temperature (7.20°C) values recorded during the height measurements. The height differences between the top flange of each Foundation Template and the Well Template reference datum were derived using the mean measured pitch and roll angles of each Template, and offsets taken from dimensional drawings and information supplied by Conoco, after taking account of the buoyancy of each MicroNav in its shock mount.

Template	Height at Top Flange Centre above Well Template Reference Datum
F1	1674 mm
F2	1685 mm
F3	1820 mm
F4	1884 mm

7.4.2 Measurement Accuracy: Errors arising from the Digiquartz sensor and various other factors are summarised below:

Errors Associated with the sensors:

Since all the sensors had been "aged" by Sonardyne for at least 3 months prior to use, and had been matched under similar pressure conditions to that at Hutton, it is considered that relative height measurements over a limited range were within 3 millibar. In standard homogenous sea water this represents 28.7 mm.

Errors not Connected with the Sensors:

a) MicroNav machining tolerance - 0.25mm.
b) MicroNav shock frame hysteresis - 0.25mm.
c) Buoyancy error when immersed in water - 2.5mm.
d) The MicroNav was mounted 6500mm from the Template Centre. The compound Template levelness could be measured to within 0.20°. This represents a height error of 23mm.
e) Dimensional checks of the Template - 2.5mm.
f) The Compatt Tide Guide installation tolerance in relation to the Well Template reference datum - 2mm.
g) Environmental factors are negligible since the measurements were taken in good weather when the swell was low, and at slack water when the rate of change of depth is minimal. In addition, any tidal variations were averaged out.
h) The water density has more effect upon the relative height measurement as the height separation of the sensors increases. The density was determined from temperature and salinity measurements and any error is considered to be within 2 mm over the 2 metre height difference.
i) MicroNav measures the output frequency of the Digiquartz by counting the number of positive going edges occuring within a known period. This period was derived from the MicroNav CPU crystal. The frequency of the CPU varies by $1.6 \quad 10^6$ over the temperature range 4 to 18°C and was determined for each MicroNav.

The total error budget with individual errors added geometrically is within the target originally specified by Conoco.

SUMMARY

8.1

The positioning tolerances achieved during the installation of the Hutton TLP Foundation Templates and Well Template are well within the specifications laid down by Conoco.

8.2

The MicroNav acoustic cable-less instrumentation system, hardware and software, involving a total of seventy-six underwater units, operated throughout the 3-month field installation without any malfunctions. This performance justifies the emphasis placed by Conoco on rigorous prototype tests during the design phase, and comprehensive simulation and operational trials throughout the project.

8.3

The flexibility of the MicroNav system was fully demonstrated during pile stabbing and subsequent piling operations. This particular application had not formed part of the original scope of work, and showed the significant benefits arising from the considerable reduction in installation times which an accurate and reliable acoustic positioning system can bring to offshore sub-sea engineering tasks.

8.4

The equipment functioned satisfactorily throughout the piling operations, demonstrating the validity of the shock and vibration criteria used for the design of the various shock mounts.

8.5

The success of the acoustic telemetry link, and the very low telemetry corruption experienced throughout the project, justifies the increasing acceptance by the offshore industry of the role that acoustics can play in both monitoring and control of sub-sea operations.

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10 GLOSSARY OF TERMS

TLP	Tension Leg Platform
SSCV	Semi-submersible Crane Vessel
PAN	Programmable Acoustic Navigator
Compatt	Computing and Telemetering Transponder
CTU	Control And Telemetry Unit
TRT	Transponder Remote Transducer
SBL	Short-Baseline
ACL	Acoustic Telemetry Link
MF	Medium Frequency (20-36kHz)
HF	High Frequency (50-120kHz)
RMS	Root Mean Square

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APPLICATION OF THE MICRONAV ACOUSTIC TELEMETERING INSTRUMENTATION SYSTEM DURING THE INSTALLATION, LEVELLING, PILING AND DIMENSIONAL CHECKING OF THE HUTTON TLP TEMPLATES

ILLUSTRATION LEGENDS

Fig No.	LEGEND
1	Hutton TLP Concept
2	Plan positions of Hutton TLP Well Template and Foundation Templates
3	Hutton TLP Foundation Template during deployment (Note Guidance Frame Locating Pins and Bumpers)
4	Guidance Frame during deployment (Note Foundation Template Locating Bucket and Bumpers)
5	MicroNav in Shock Frame on a Hutton Foundation Template
6	Transponder Remote Transducers and Remote Acoustic Link Transducer in Shock Mounts on a Hutton Foundation Template
7	Remote Altimeter in Shock Mount on Guidance Frame
8	Gyro Unit and Battery Pack in Shock Mounts on Guidance Frame
9	Calibration of Attitude Reference Plate on a Hutton Foundation Template
10	Secondary Positioning Method (Installation Monitoring of Foundation Template using MicroNav SBL System relative to Well Template Transponders)
11	PAN Acoustic Transceiver and Computation Display Computer in Control Cabin on SSCV (Note ROV Video Displays)
12	Different Stages during Guidance Frame Deployment
(a)	Time - 07.05 hrs: Distance from Target : 19.7 metres Height above Target : 58.8 metres Orientation Offset : -9.2 degrees Attitude Offset : Pitch +1.2 degrees Roll -0.3 degrees
(b)	Time 08.28 hrs: Distance from Target : 1.6 metres Height above Target : 8.5 metres Orientation Offset : -1.4 degrees Attitude Offset : Pitch +1.5 degrees Roll -0.5 degrees

APPLICATION OF THE MICRONAV ACOUSTIC TELEMETERING INSTRUMENTATION SYSTEM DURING THE INSTALLATION, LEVELLING, PILING AND DIMENSIONAL CHECKING OF THE HUTTON TLP TEMPLATES

13 Different Stages during Deployment of a Hutton Foundation Template

(a) 20:41 hrs:

Distance from Target : 13.0 metres
Height above Target : 81.8 metres
Orientation Offset : -9.0 degrees
Attitude Offset : Pitch +1.2 degrees
Roll +0.8 degrees

(b) 21:21 hrs:

Distance from Target : 1.0 metre
Height above Target : 1.0 metre
Orientation Offset : -0.3 degrees
Attitude Offset : Pitch ±1.1 degrees
Roll ±0.7 degrees

14 Attitude of Hutton Foundation Template F4 Before and After Jacking Operations

(a) Before Jacking:
Average Roll : 0.02 degrees
Average Pitch : 0.48 degrees

(b) After Jacking:

Average Roll : 0.03 degrees
Average Pitch : 0.16 degrees

15 Sub Miniature Transponder mounted on Menck Underwater Hammer Power Pack

16 Monitoring Position of Tension pile during Stabbing Operations

TABLE 1 COMPARISON BETWEEN "AS BUILT" AND ACOUSTIC MEASUREMENTS ON HUTTON GUIDANCE FRAME

DIMENSION	"AS BUILT" MEASUREMENTS 'T'(metres)	ACOUSTIC MEASUREMENTS		DIFFERENCE O – T (metres)
		OBSERVED 'O'(metres)	STND.DEVIATION (metres)	
5A(1)-5A(2)	48.875	48.847	0.002	-0.03
5A(2)-5A(4)	88.635	88.643	0.006	+0.01
5A(3)-5A(4)	73.477	73.440	0.006	-0.04
5B(1)-5B(2)	73.460	73.471	0.004	+0.01
5B(1)-5B(3)	88.647	88.674	0.009	+0.03
5B(3)-5B(4)	48.836	48.815	0.003	-0.02
6A(1)-6A(4)	58.705	58.748	0.003	+0.04
6B(1)-6B(4)	59.795	59.814	0.004	+0.02
5A(1)-5B(1)	49.156	49.128	0.002	-0.03
5A(2)-5B(2)	73.882	73.859	0.003	-0.02
5A(2)-5B(3)	89.068	89.072	0.004	+0.00
5A(3)-5B(2)	58.724	58.678	0.003	-0.05
5A(3)-6A(1)	76.470	76.495	0.003	+0.03
5A(3)-6B(1)	76.980	76.960	0.003	-0.02
5A(4)-5B(4)	49.098	49.070	0.002	-0.03
5B(2)-6B(4)	76.995	76.971	0.004	-0.02

(Water Temperature - 6.85 ±0.1°C; Water Salinity - 35.28 ±0.05ppt; Water Depth - 142 ± 0.5 metres : Computed Acoustic Propagation Velocity 1480.9 ±0.4 metre/sec)

NOTE: 5A(1)-5B(2) refers to the distance from TRT, Channel 1, of MicroNav 5A to TRT, Channel 2, of MicroNav 5B.

TABLE 2 COMPARISON OF THEORETICAL DIMENSIONS (ASSUMING PERFECT DEPLOYMENT) AND ACOUSTIC MEASUREMENTS BETWEEN HUTTON FOUNDATION TEMPLATES

TEMPLATE	DIMENSION	THEORETICAL MEASUREMENTS(T) (metres)	ACOUSTIC MEASUREMENTS		DIFFERENCE O - T (metres)
			OBSERVED(O) (metres)	SD (metres)	
F1-F2	1(2)-2(1)	55.385	55.432	0.004	+0.05
	1(2)-2(4)	58.952	59.000	0.004	+0.05
	1(3)-2(1)	58.971	59.060	0.009	+0.09
	1(3)-2(4)	58.764	58.822	0.003	+0.06
F1-F3	1(4)-3(4)	56.842	56.901	0.010	+0.06
	1(4)-3(3)	54.760	54.779	0.009	+0.02
	1(3)-3(3)	56.836	56.820	0.008	-0.02
F1-F4	1(2)-4(4)	100.356	100.495*	0.005	+0.14
	1(2)-4(3)	89.996	89.998	0.005	+0.00
	1(3)-4(3)	80.341	80.332	0.007	-0.01
F2-F3	2(1)-3(4)	89.971	90.030	0.004	+0.06
	2(4)-3(4)	80.323	80.366	0.002	+0.04
F2-F4	2(4)-4(4)	56.868	56.817	0.003	-0.05
	2(4)-4(3)	54.776	54.773	0.006	-0.00
	2(3)-4(4)	54.786	54.789	0.006	+0.00
	2(3)-4(3)	56.855	56.910	0.011	+0.05
F3-F4	3(1)-4(3)	58.950	59.002	0.002	+0.05
	3(1)-4(2)	55.385	55.420	0.002	+0.03
	3(4)-4(2)	58.971	58.987	0.003	+0.02

(Note: 1(2)-4(3) refers to distance from TRT, Channel 2, of MicroNav 1A or 1B to TRT, Channel 3, of MicroNav 4A or 4B)

* Value rejected during the final least squares adjustment

TABLE 3 COMPARISON OF THEORETICAL DIMENSIONS (ASSUMING PERFECT DEPLOYMENT) AND ACOUSTIC MEASUREMENTS BETWEEN HUTTON FOUNDATION AND WELL TEMPLATES

WELL TEMPLATE TRANSPONDER	FOUNDATION TEMPLATE TRT (metres)	THEORETICAL MEAS.(T) (metres)	ACOUSTIC MEASUREMENTS		DIFFERENCE (O - T)
			OBSERVED (metres)	SD (metres)	
7	1(2)	60.211	60.99*	0.05	+0.78
	2(1)	72.964	73.12	0.03	+0.16
	2(4)	62.867	61.48*	0.04	-1.39
	3(4)	18.059	18.11	0.04	+0.05
8	2(1)	60.186	59.94*	0.17	-0.25
	2(3)	52.589	53.02	0.08	+0.03
	4(3)	18.075	18.03	0.03	+0.02
	4(4)	31.404	31.42	0.08	-0.05
9	2(1)	71.474	71.52	0.02	+0.05
	2(4)	57.328	57.43	0.05	+0.10
	2(3)	62.721	62.65	0.10	-0.07
	4(3)	13.661	13.61	0.03	-0.04
	4(2)	18.309	18.30	0.03	-0.01
	3(1)	45.612	45.60	0.04	-0.01
10	4(2)	45.714	45.72	0.04	+0.01
	3(1)	18.263	18.28	0.04	+0.02
	3(4)	13.580	13.66	0.03	+0.08

(Note: 1(2) refers to TRT, Channel 2, or MicroNav 2B)

* Values rejected during the final least squares adjustment

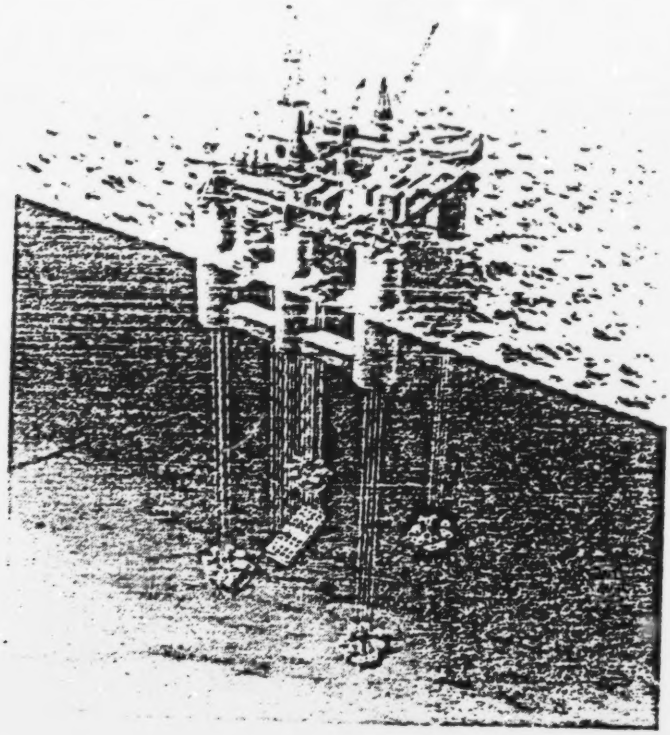
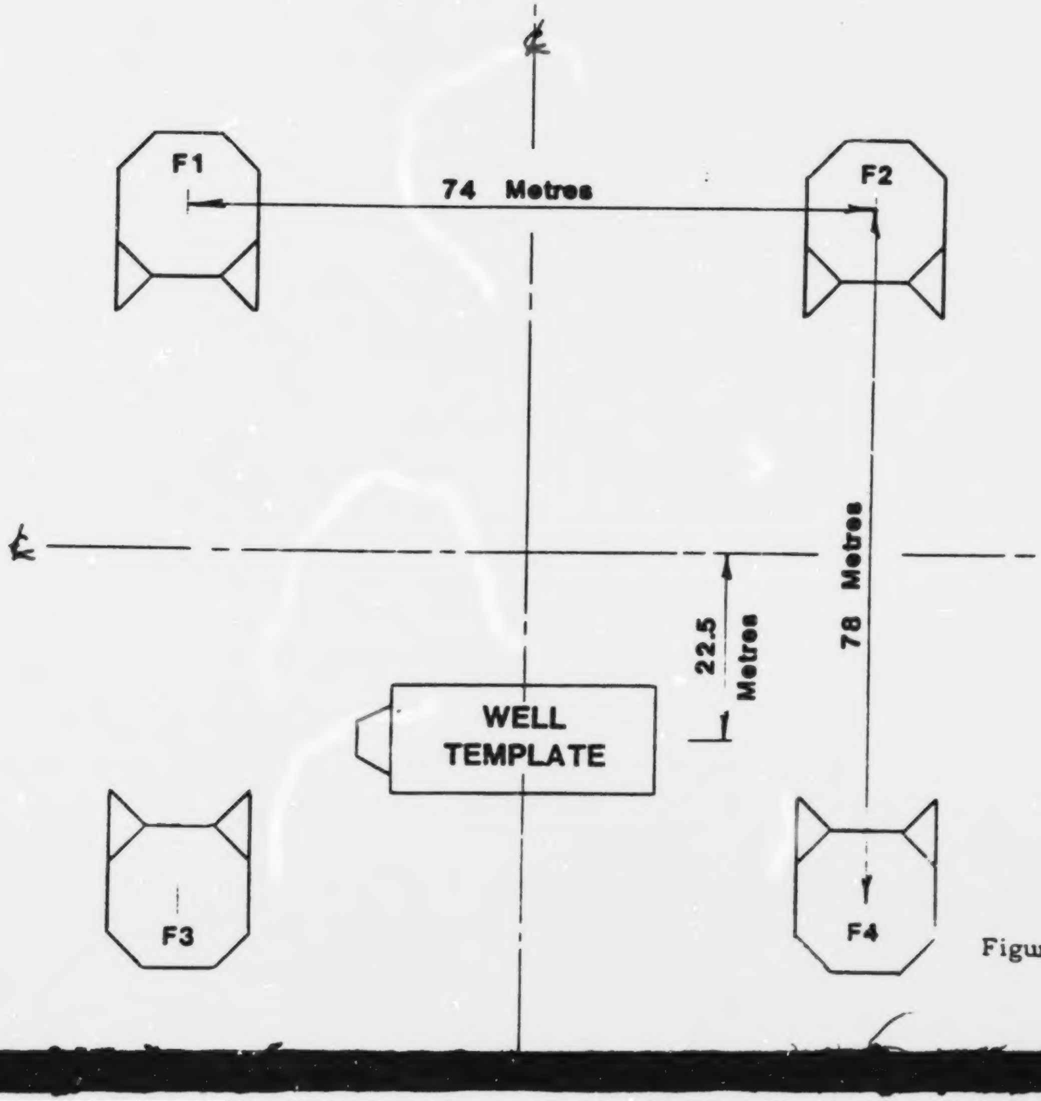
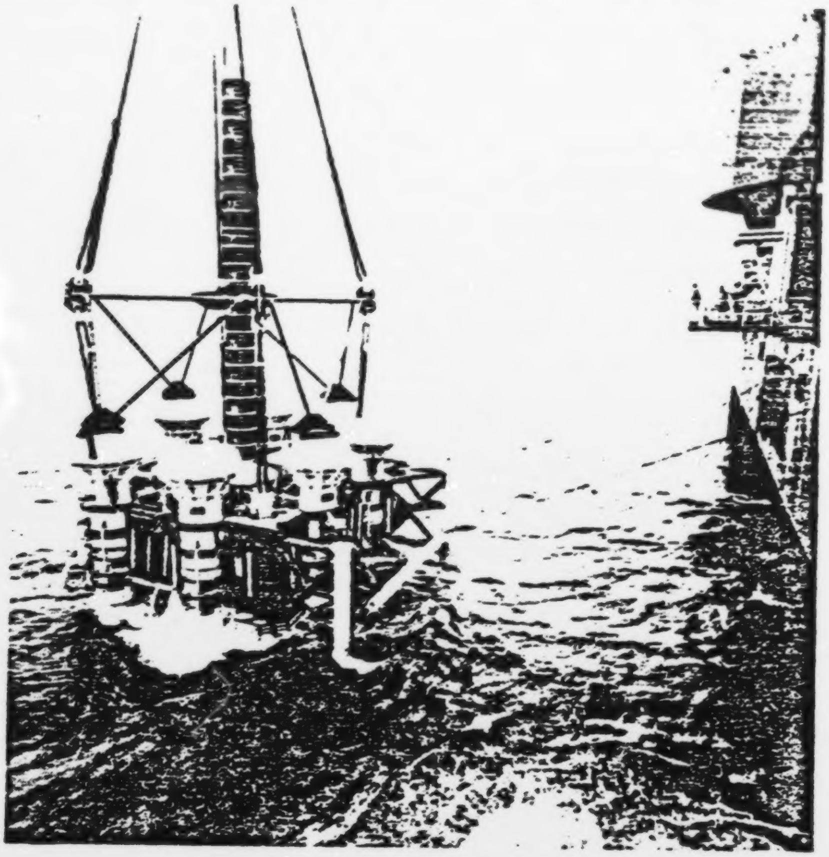


Figure 1



℄
F1
74 Metres
F2
℄
78 Metres
22.5 Metres
WELL TEMPLATE
F3
F4

Figure 2



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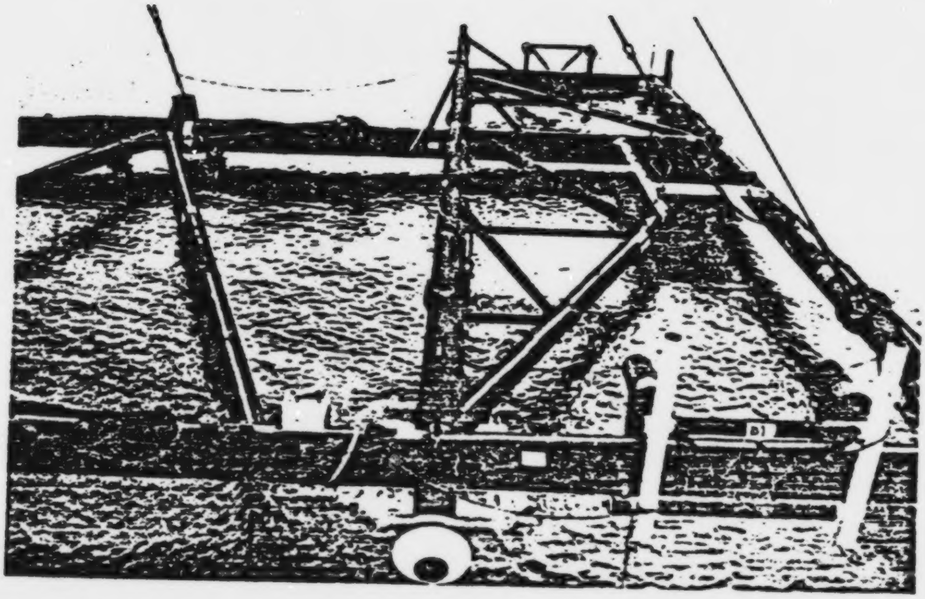

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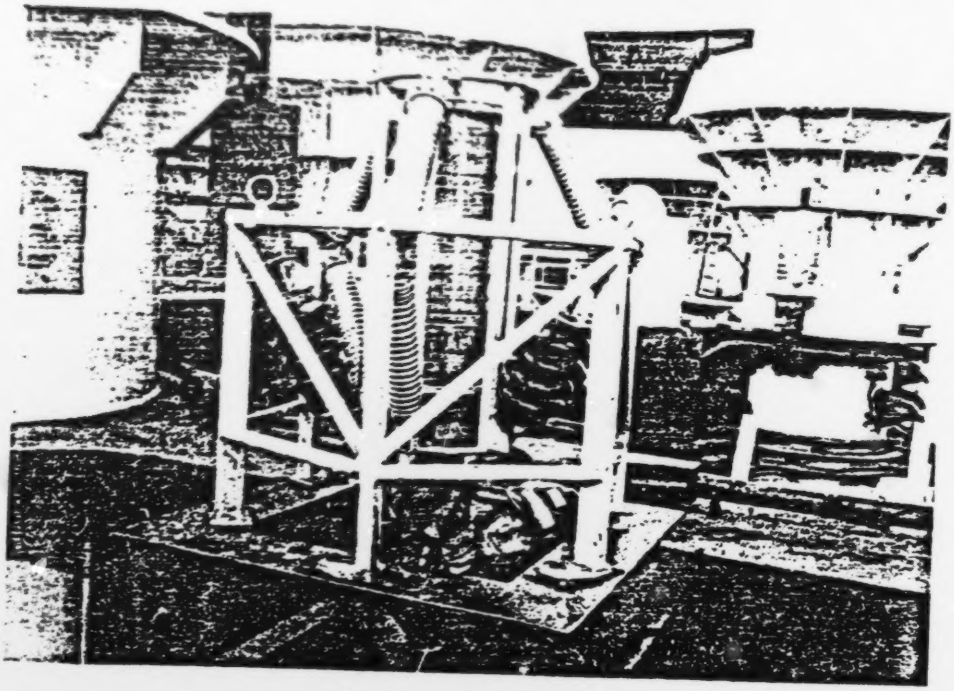
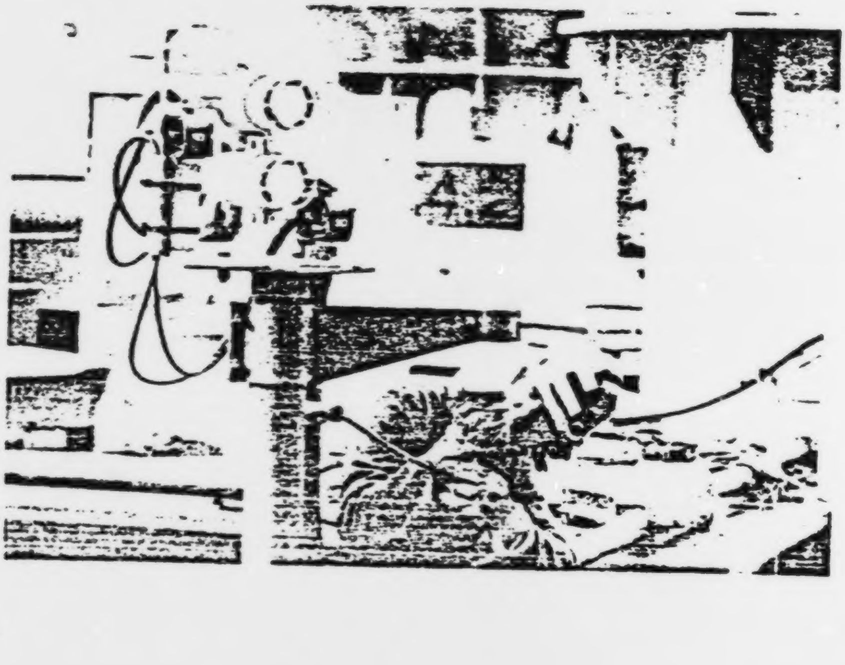


Figure 5



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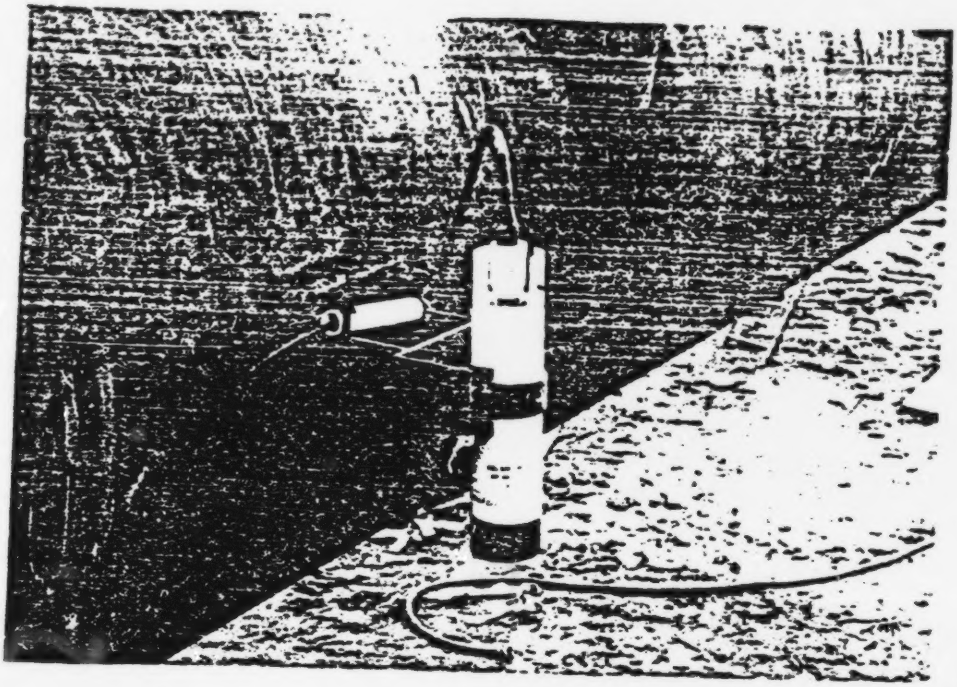
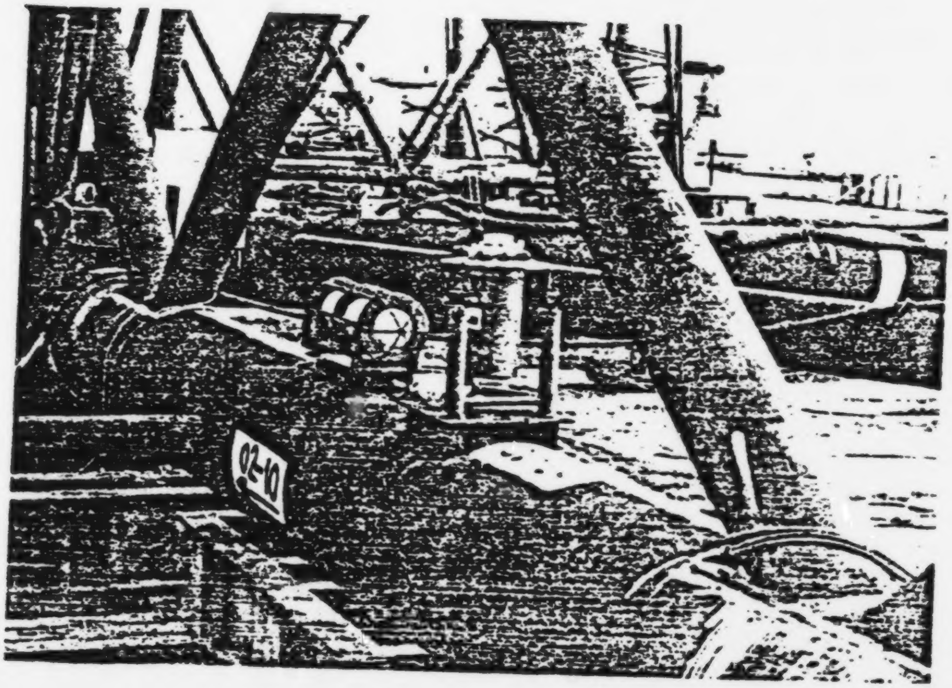


Figure 7



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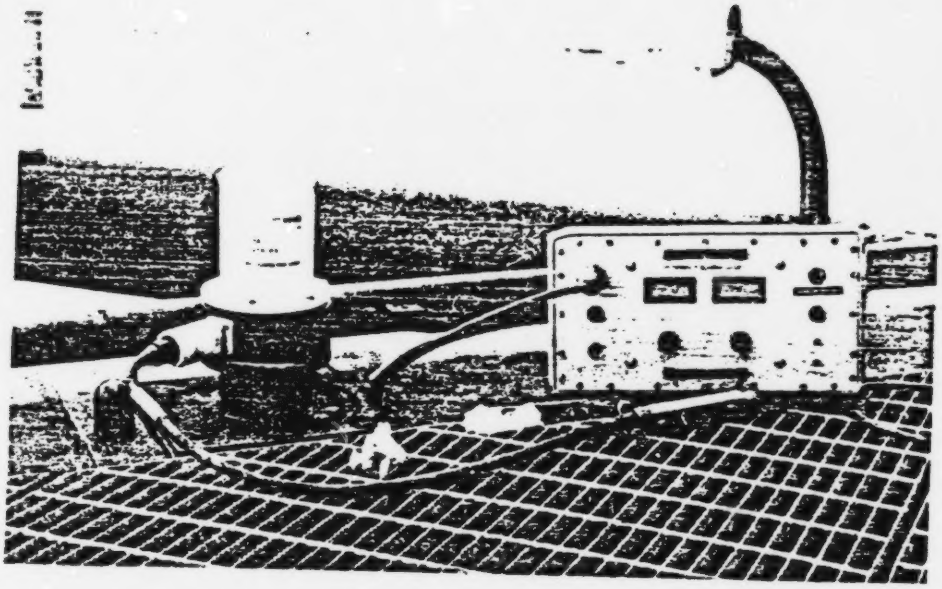


Figure 9

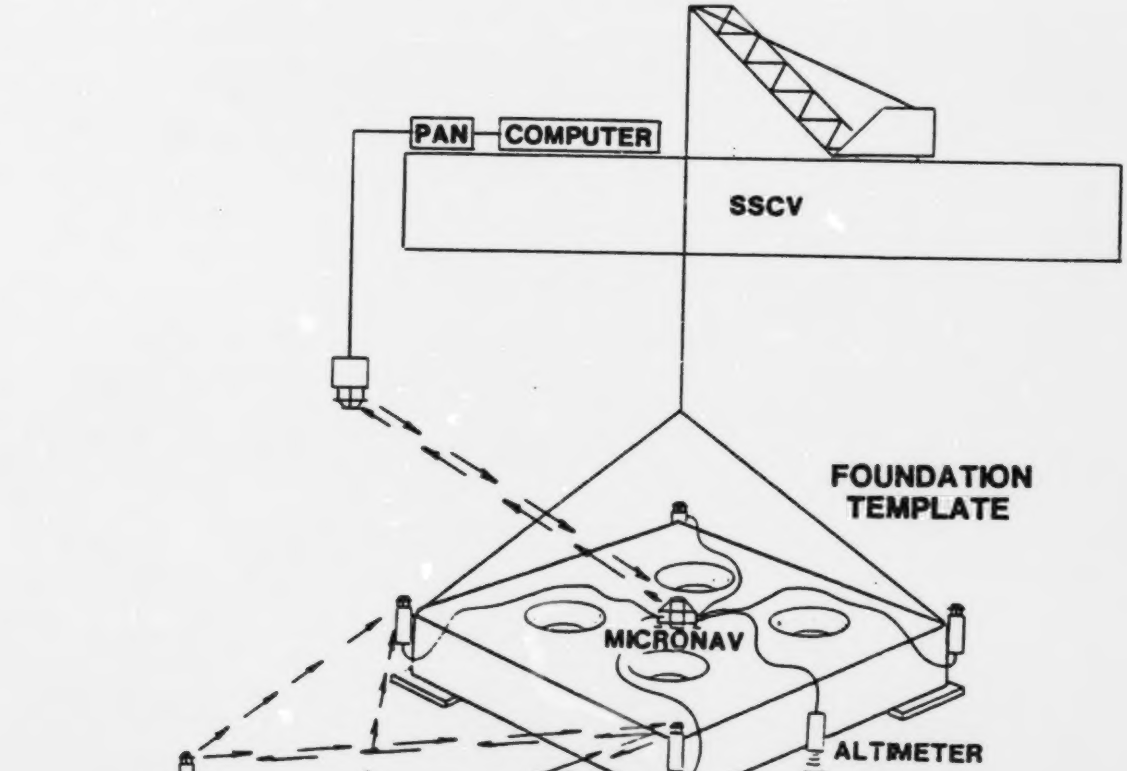

PAN
COMPUTER
SSCV
FOUNDATION TEMPLATE
MICRONAV
ALTMETER
MASTER TRT
WELL TEMPLATE
TRANSPONDER

Figure 10

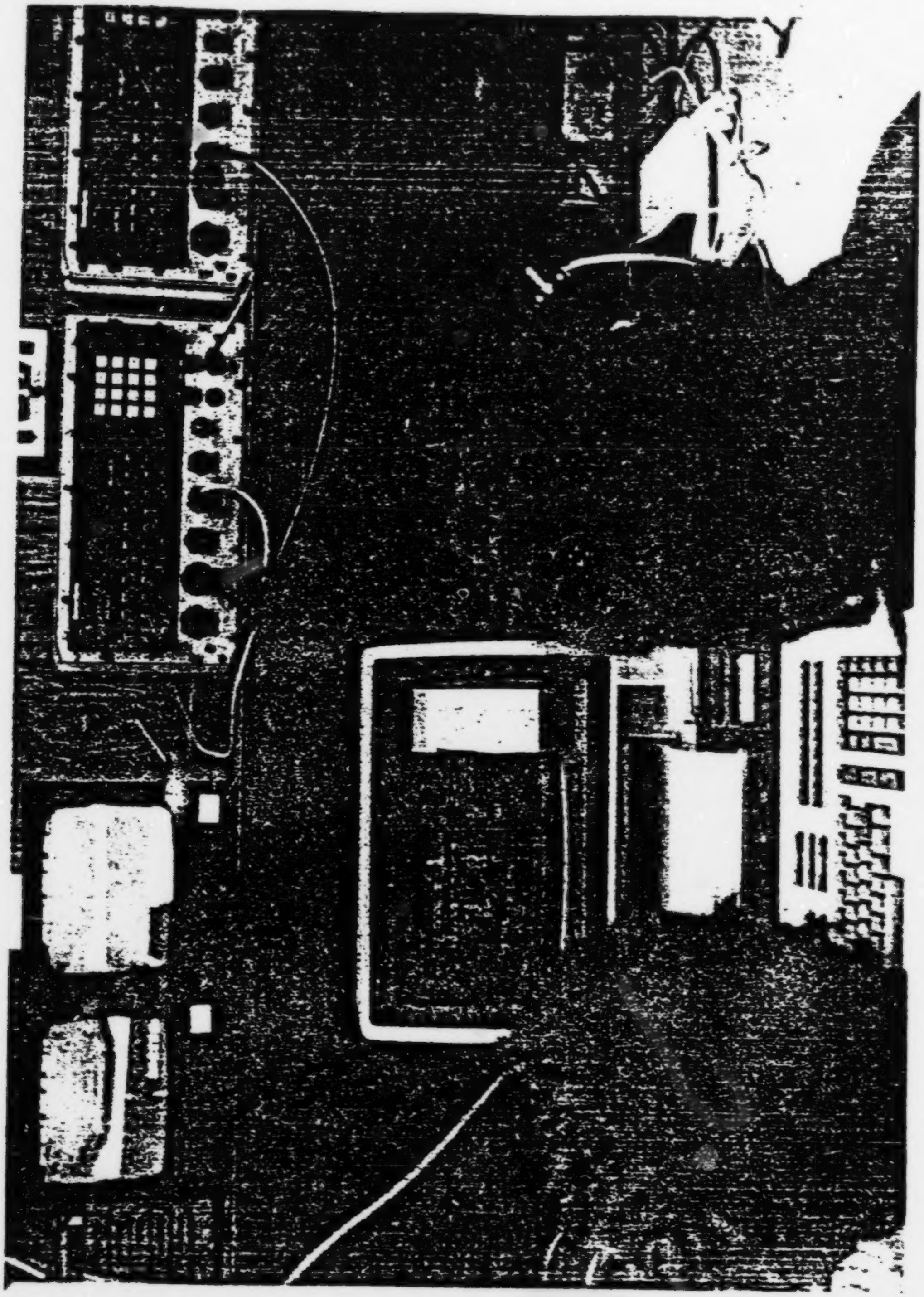
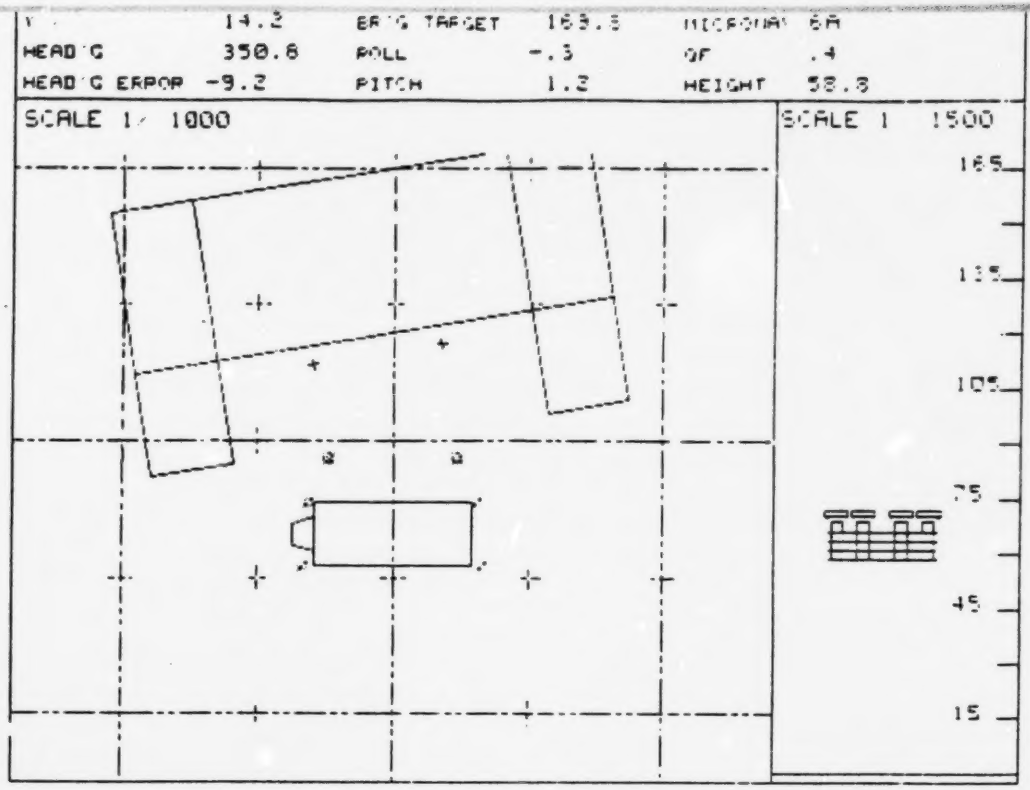


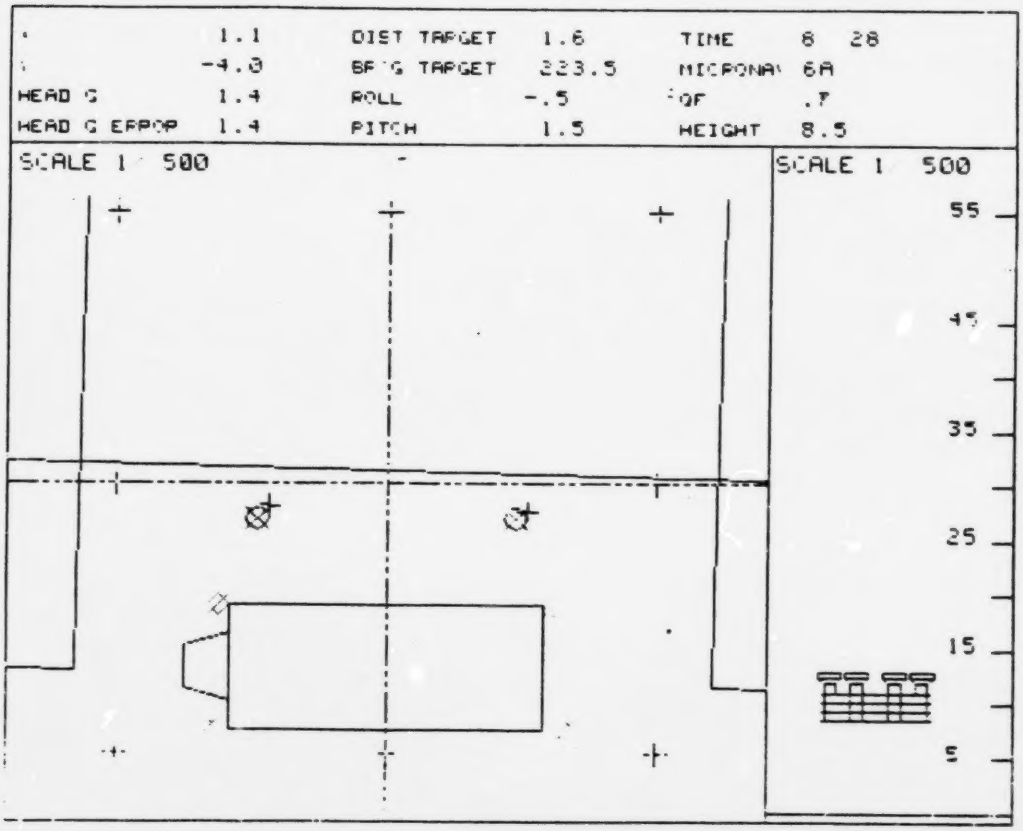
Figure 11



```
Y                14.2    BR G TARGET    163.3    MICRONAV 6A
HEAD G          350.8    ROLL             -.3    OF       .4
HEAD G ERROR     -9.2    PITCH            1.2    HEIGHT   58.8
```

SCALE 1/ 1000
SCALE 1 1500
165
135
105
75
45
15

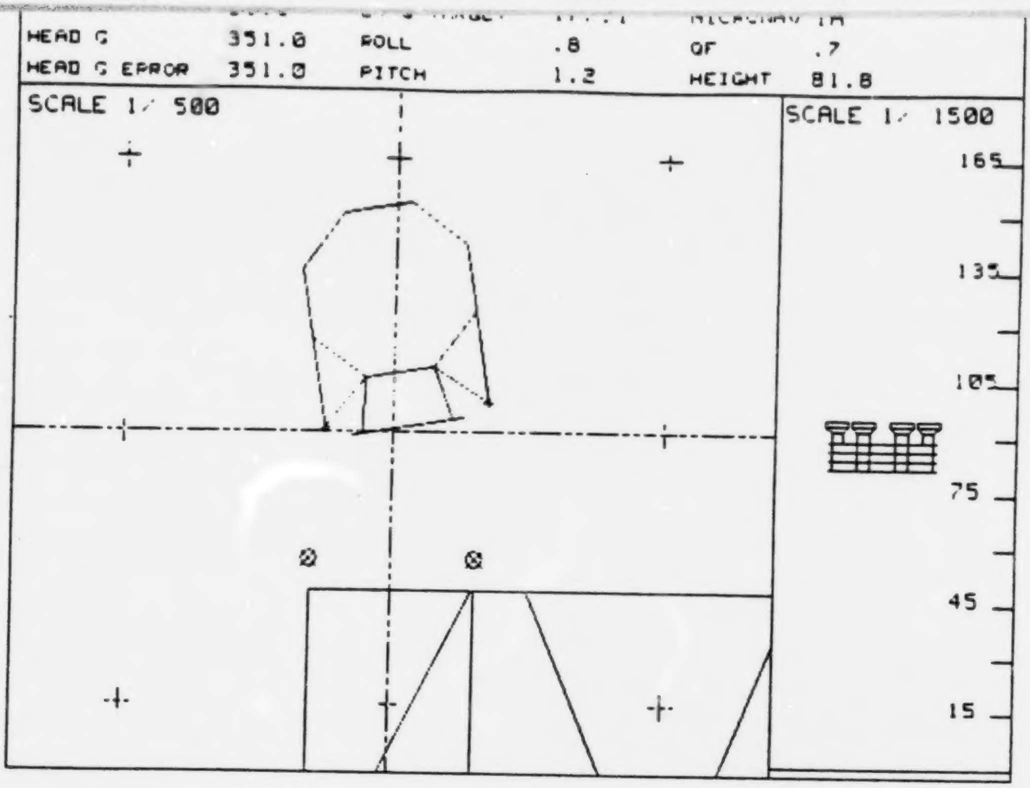
Figure 12a



```
                  1.1    DIST TARGET      1.6    TIME     8 28
                 -4.0    BR G TARGET    223.5    MICRONAV 6A
HEAD G            1.4    ROLL             -.5    OF       .7
HEAD G ERROR      1.4    PITCH            1.5    HEIGHT   8.5
```

SCALE 1 500
SCALE 1 500
55
45
35
25
15
5

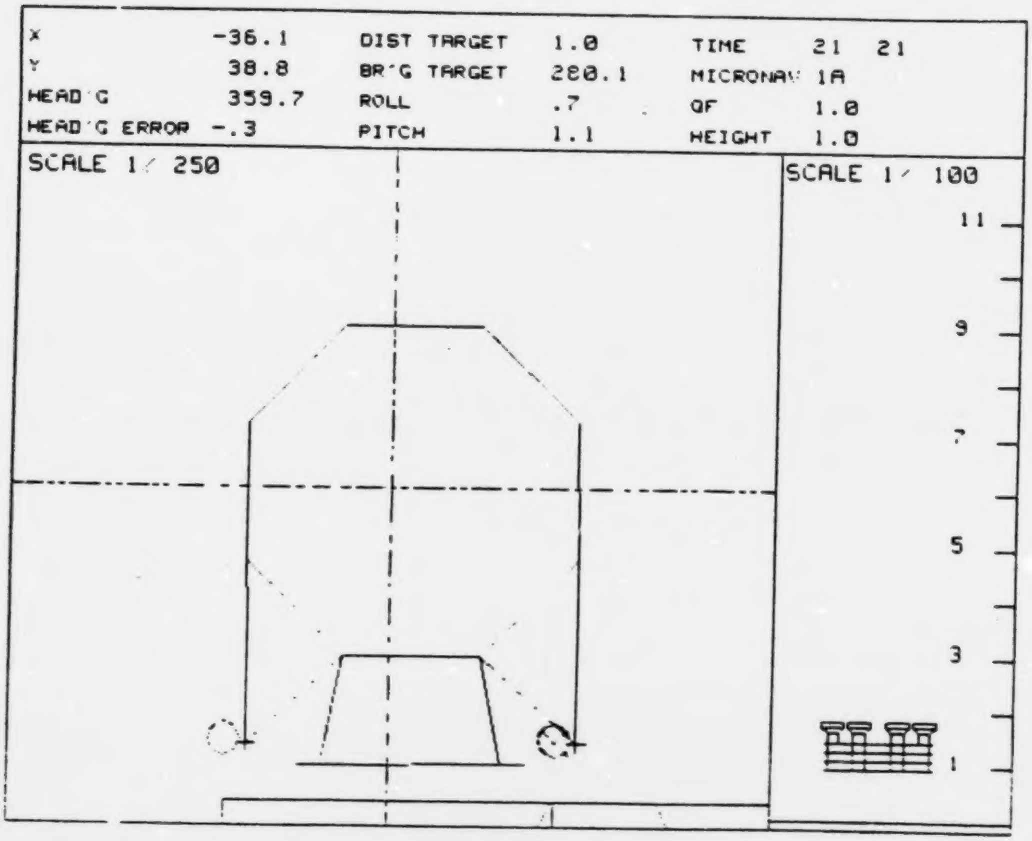
Figure 12b



```
HEAD G          351.0   ROLL       .8      OF       .7
HEAD G ERROR    351.0   PITCH     1.2      HEIGHT   81.8
```

SCALE 1/ 500
SCALE 1/ 1500
165
135
105
75
45
15

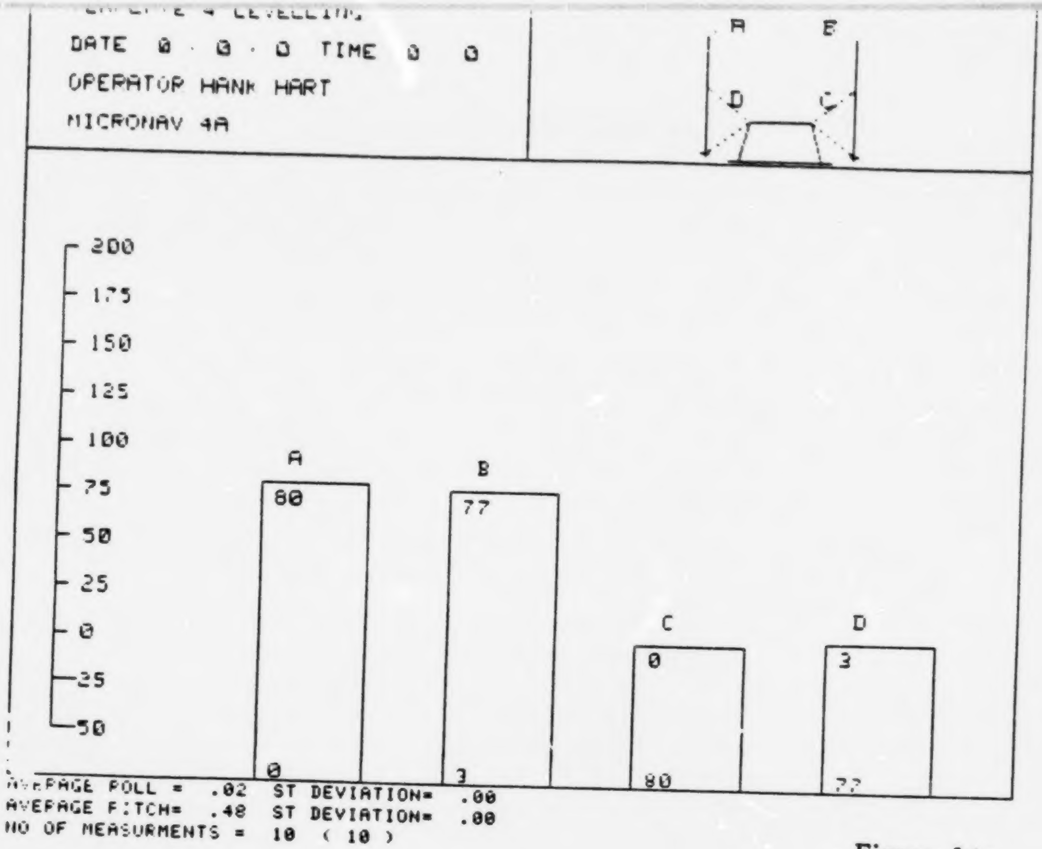
Figure 13a



```
X               -36.1   DIST TARGET   1.0     TIME      21  21
Y                38.8   BR'G TARGET   280.1   MICRONAV  1A
HEAD'G          359.7   ROLL          .7      OF        1.0
HEAD'G ERROR    -.3     PITCH         1.1     HEIGHT    1.0
```

SCALE 1/ 250
SCALE 1/ 100
11
9
7
5
3
1

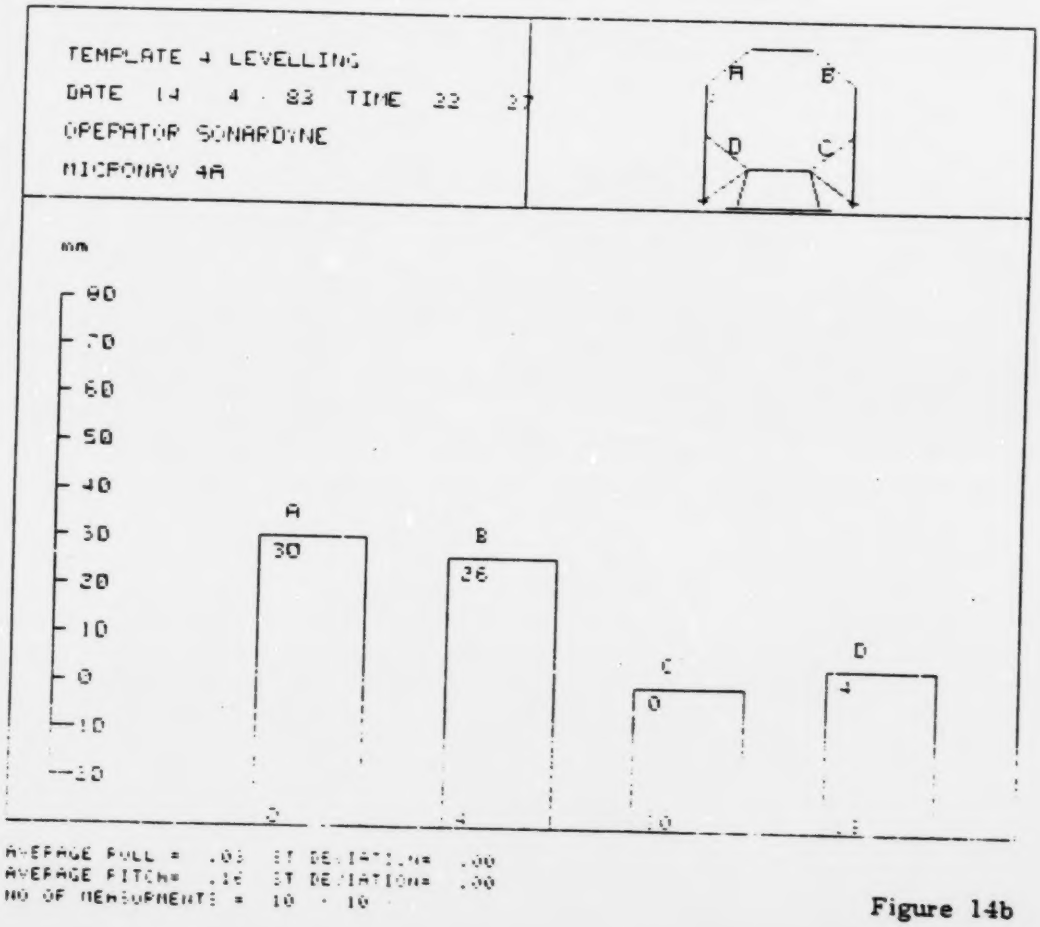
Figure 13b



TEMPLATE 4 LEVELLING
DATE 0 . 0 . 0 TIME 0 0
OPERATOR HANK HART
MICRONAV 4A

AVERAGE ROLL = .02 ST DEVIATION= .00
AVERAGE PITCH= .48 ST DEVIATION= .00
NO OF MEASURMENTS = 10 (10)

Figure 14a

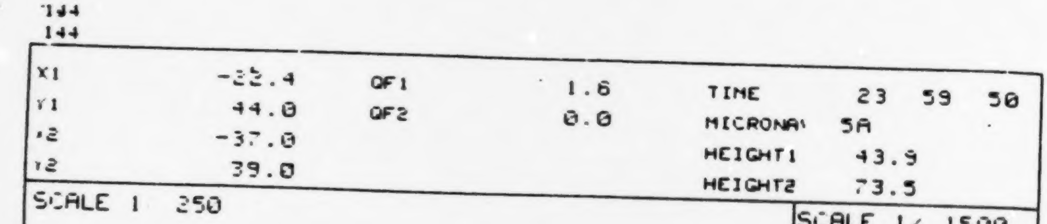


TEMPLATE 4 LEVELLING
DATE 14 . 4 . 83 TIME 22 27
OPERATOR SONARDYNE
MICRONAV 4A

AVERAGE ROLL = .03 ST DEVIATION= .00
AVERAGE PITCH= .16 ST DEVIATION= .00
NO OF MEASURMENTS = 10 (10)

Figure 14b

Figure 15



```
144
144
X1            -25.4     QF1          1.6      TIME        23   59   50
Y1             44.0     QF2          0.0      MICRONAV    5A
X2            -37.0                           HEIGHT1     43.9
Y2             39.0                           HEIGHT2     73.5
```

SCALE 1 250
SCALE 1/ 1500
165
135
105
75
45
15

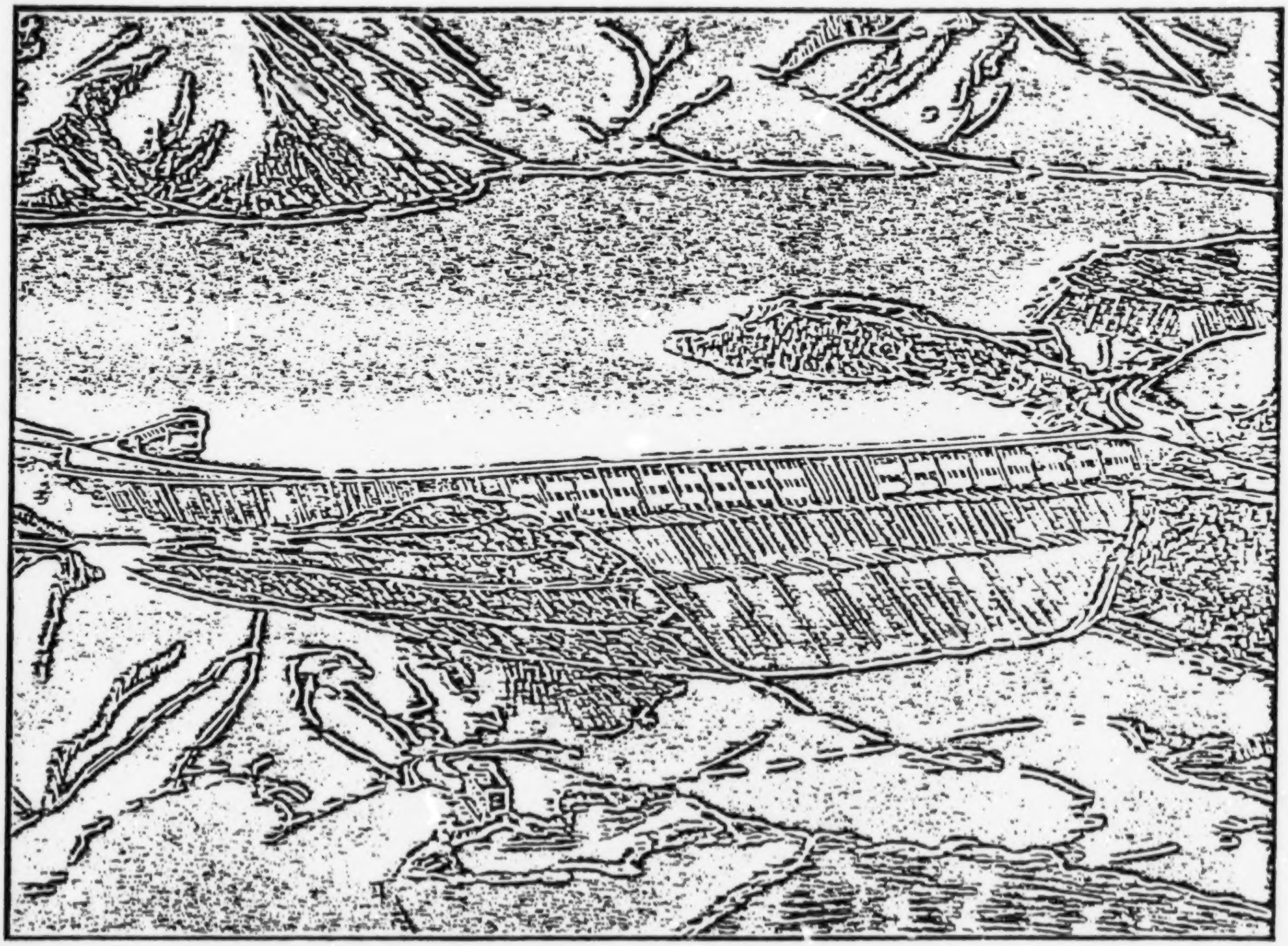
Figure 16

APPENDIX 7

7-1 Equipment Information

1. Sinco Strain Meters
2. Sinco Borehole Extensometers
3. Sinco Digitilt Tiltometers
4. Sinco In-Place Inclinometer
5. Setra Systems; Pressure Transducers and Transmitters
6. Analog Devices - Process to Computer Interface
7. Analog Devices - MACSYM Computer
8. Sinco Digitilt Inclinometer
9. Humphrey Directional Surveyor Systems

STRAIN METERS



SiNCO

slope indicator company

Model 51701

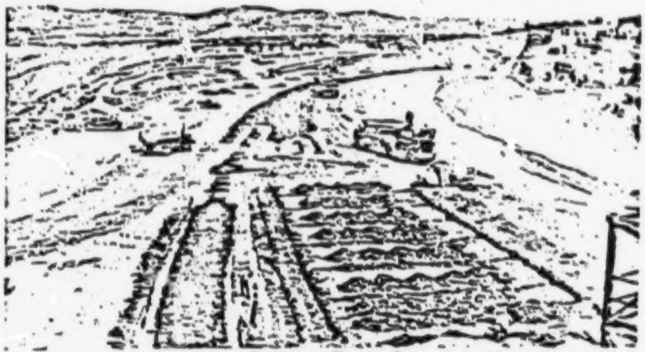
STRAIN METER

for earth structure deformation

- Linear potentiometer conductive plastic sensing elements
- Waterproof, direct-burial units
- Preassembled gauge lengths
- Optional measurement range and gauge lengths
- Rugged construction
- Portable digital indicator or automatic monitoring

Deformation in earth structures over an indefinite horizontal distance can be measured using the Model 51701 Strain Meter. These instruments are precision electrical displacement sensors which can be read remotely at a central point by means of portable indicators or by automatic data logging monitors. The Strain Meters have optional gauge lengths covering several feet. The sensors measure the change in gauge length linearly over a distance of several inches with a sensitivity of 10^{-3} times the range.

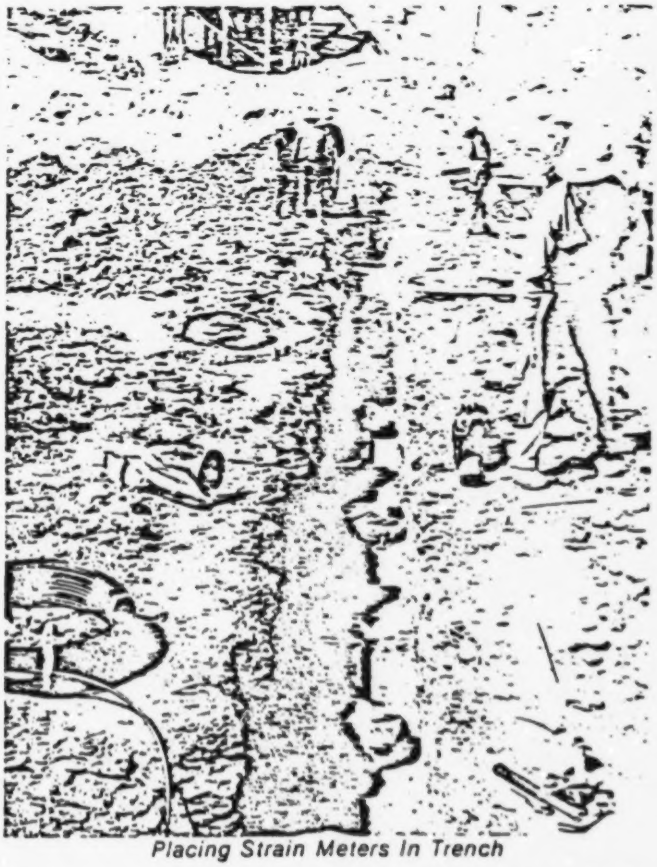
The Strain Meters are waterproof and designed for long-term operation buried within earth embankments such as dams, highways and reinforced earth structures. A typical installation in an earth dam is shown in the pictorial diagram. The Strain Meters are installed end-to-end, in line, and attached to each other in a continuous string to cover the total distance in the structure to be monitored.



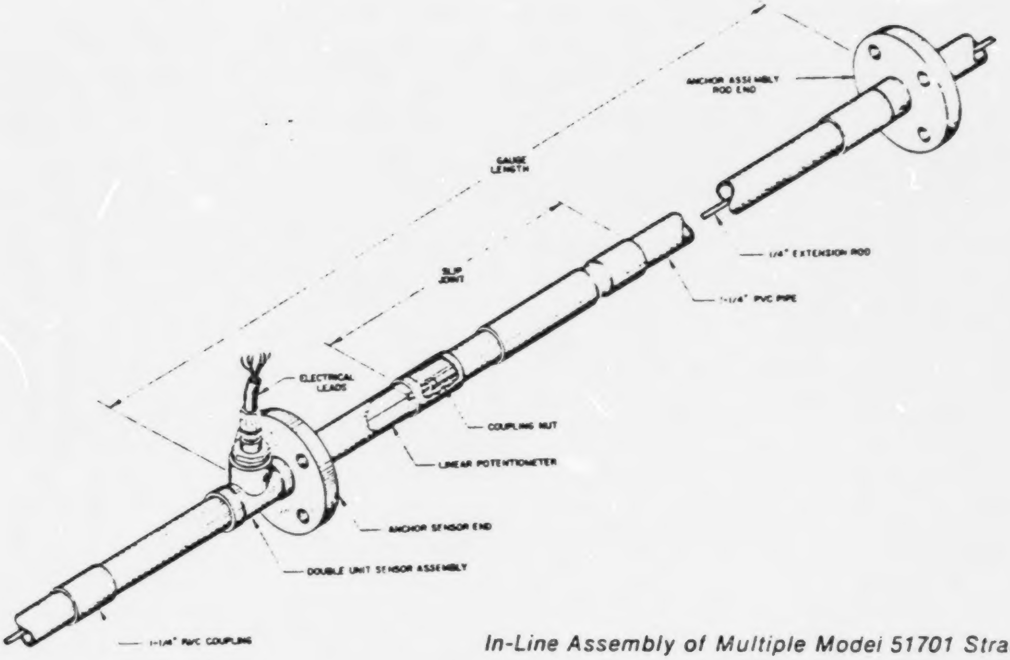
Installation During Dam Construction

DESCRIPTION AND SPECIFICATIONS

The sensing element is a linear potentiometer which has a resistance element of conductive plastic. The potentiometer and its electrical connections are potted and sealed within a protective enclosure of PVC pipe. A rod 1/4 inch in diameter connects the potentiometer shaft to the anchor point. The rod material is normally stainless steel. To eliminate temperature effects on long lengths, Invar rod is used. The rod is enclosed within PVC pipe. As shown for the 51701, two potentiometers are installed at the same anchor point. One 5-conductor cable for the two units is brought out the side of the double unit assembly through a PVC pipe tee. The standard cable is enclosed within 1/2 inch polyethylene tubing from Strain Meter to terminal



Placing Strain Meters In Trench


ANCHOR ASSEMBLY ROD END
GAUGE LENGTH
SLIP JOINT
1/4" EXTENSION ROD
1-1/4" PVC PIPE
ELECTRICAL LEADS
COUPLING NUT
LINEAR POTENTIOMETER
ANCHOR SENSOR END
DOUBLE UNIT SENSOR ASSEMBLY
1-1/4" PVC COUPLING

In-Line Assembly of Multiple Model 51701 Strain Meters

tation. As an option, the cable may be enclosed in ½-inch flexible steel conduit with waterproof PVC jacket.

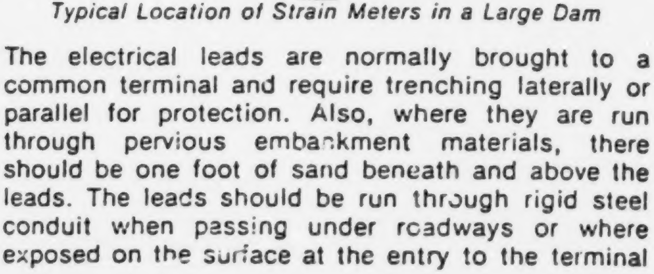
The displacement range of the sensors is optional and can be selected to meet requirements for measurements in rock or soil. The basic sensing unit is adaptable to other uses such as monitoring slope stability and structural joint movement.

The gauge length of the Strain Meters is optional; however, standard lengths are in 5-foot multiples.

APPLICATION AND INSTALLATION

The Strain Meters are particularly useful for monitoring strains in large earth structures. A number of large earth dams have developed cracks across the core soon after construction and during first filling of the reservoir. This cracking generally occurs near the abutments as a result of differential settlement and is frequently associated with irregularities in the underlying abutment rock. Sharp changes in slope resulting from abutment excavation may also contribute to tension cracking of the core. The 51701 Strain Meter, installed at critical locations, makes possible early detection and facilitates remedial work contributing to the safety and integrity of the structure. The Strain Meters are placed in a continuous straight line, end to end, with one end of the string anchored in the abutment. Such strings with multiple Strain Meters form an instrumentation system which is able to locate cracks within any of the gauge lengths.

To install the strain meters, a trench is excavated in the embankment surface three to four feet deep, 14 inches wide, with a level bottom. Lateral cutouts are made at the anchor points if extensions are used. Lateral trenches are made for the electrical cable. To minimize time at the site, the Strain Meters are pre-assembled to 50-foot lengths on a flatbed trailer. These are transported to the site and placed on boards spanning the trench at 10-foot intervals. Final adjustments of the initial setting are made as the entire string is connected together. It is then lowered to the bottom of the trench gradually by means of rope slings at each board. A 3- to 6-inch layer of screened core material is placed beneath and above the instrument if installed in the impervious core of a dam. Otherwise, fine sand should be used. Backfilling is completed using excavated material and should be carefully done using hand tools.


Sta 10+67
Sta 12+87
CREST OF DAM EL 855
EL 845
22 Strainmeters
EL 810
13 Strainmeters
Sta 11+57
Sta 27+15
Sta 30+15
EL 845
30 Strainmeters
EL 810
25 Strainmeters
Sta 29+60

Typical Location of Strain Meters in a Large Dam

The electrical leads are normally brought to a common terminal and require trenching laterally or parallel for protection. Also, where they are run through pervious embankment materials, there should be one foot of sand beneath and above the leads. The leads should be run through rigid steel conduit when passing under roadways or where exposed on the surface at the entry to the terminal box. A suitable house enclosing the terminal boxes should be provided for protection.

Some of the large earth structures in which the strain meter is being used to monitor potential deformation includes the following:

New Don Pedro Dam, California
Mica Dam, British Columbia
Ludington Pumped Storage Reservoir, Michigan
Tarbela Dam, Pakistan
Keban Dam, Turkey
Bayano Dam, Panama
Reinforced Earth Highway Embankment, California
La Grande Hydro Project, Quebec
Gathright Dam, Virginia

MONITORING INSTRUMENTS

Readings of strain meter outputs may be made manually by means of portable battery operated indicators, Models 51811 or 51762. These units are connected to remote terminal stations by means of a multi-conductor jumper cable. Automatic data logging equipment may be interfaced to have the capability of digital printout of all data, threshold comparison, alarm triggering, and also transmission of data via telephone line to office printout equipment.

SPECIFICATIONS

Sensor Resolution and Hysteresis: 0.1% Full Scale range

Sensor Linearity: 1.0% Full Scale range

Sensor Resistance: 10 K ohms

Sensor Output: Resistance ratio

Measurement Range: 6 in. standard (152 mm). Other ranges optional.

Gauge Length—Standard gauge length assemblies

51719	5 feet (152 cm)
51713	10 feet (305 cm)
51760	15 feet (457 cm)
51761	20 feet (610 cm)
51759	25 feet (762 cm)

Effect of Cable Length: .04% Full Scale/1000 feet

Temperature Effect on Sensors: None

Temperature Effect on Cable: 0.0001% Full Scale /°F/1000 feet

Housing Material: 1-1/4" schedule 40 PVC pipe

Outside Diameter: 1.66 in. (42 mm)

Reaction Flange at Anchor Point: Standard anchor is 1-1/4 in. schedule 40 PVC pipe floor flange, 4-5/8 in. dia. (117 mm).

Anchor Extensions: May be bolted to reaction flange to increase embedment coupling with compacted soil.

Aluminum angle P/N 51737, 1-1/2 in. x 1-1/4 in. x 1/8 in. x 24 in. (38 mm x 32 mm x 3 mm x 610 mm)

PVC plate P/N 51738, 10-1/2 in. x 8 in. x 5/8 in., (262 mm x 203 mm x 16 mm)

PVC plate P/N 51757, 11-7/8 in. dia. x 5/8 in., (301 mm x 16 mm)

Sensor Assemblies:

Single sensor assembly, Part No. 51749 used at the end of in-line string of Strain Meters.

Double sensor assembly, Part No. 51711 used at intermediate locations of in-line string of strain meters.

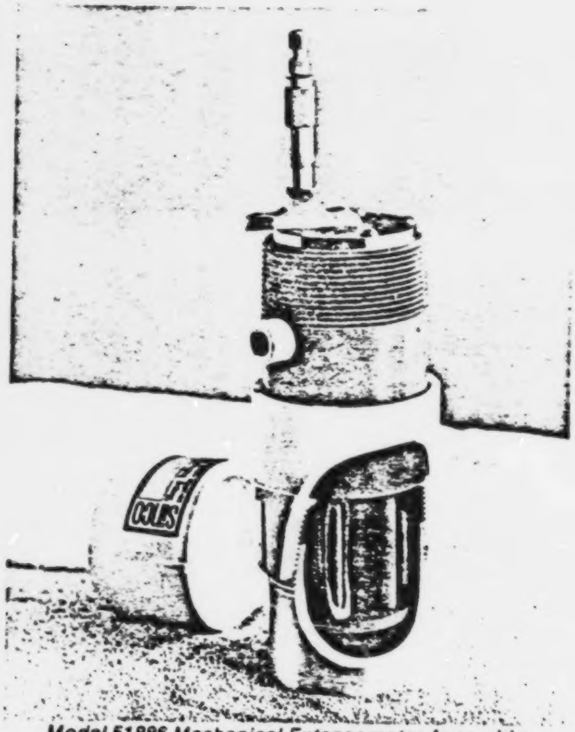
SINCO
Slope Indicator Company
3668 Albion Place North, Seattle, Washington 98103 U.S.A.
TWX: 910-444-2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073

Printed in USA (8-77)

Borehole Extensometer

multi-position, rod type

The Multi-Position Borehole Extensometer Assembly is a precision instrument designed to measure strain within earth and rock masses. This assembly can be readily installed in a 3-inch diameter (NX) borehole. It is capable of measuring large strains with a sensitivity of as little as 0.001 inch axial movement from five positions within the borehole. The installation can be horizontal, inclined or vertical. The assembly can be sensed either mechanically or electrically.



Model 51886 Mechanical Extensometer Assembly

The Extensometer Assembly, Model 51886, consists of a Reference Head (mechanical) with stainless steel reference plate, depth micrometer, fixed anchors, connecting rods and protective tubes. A typical installation, is shown in Fig. 1.

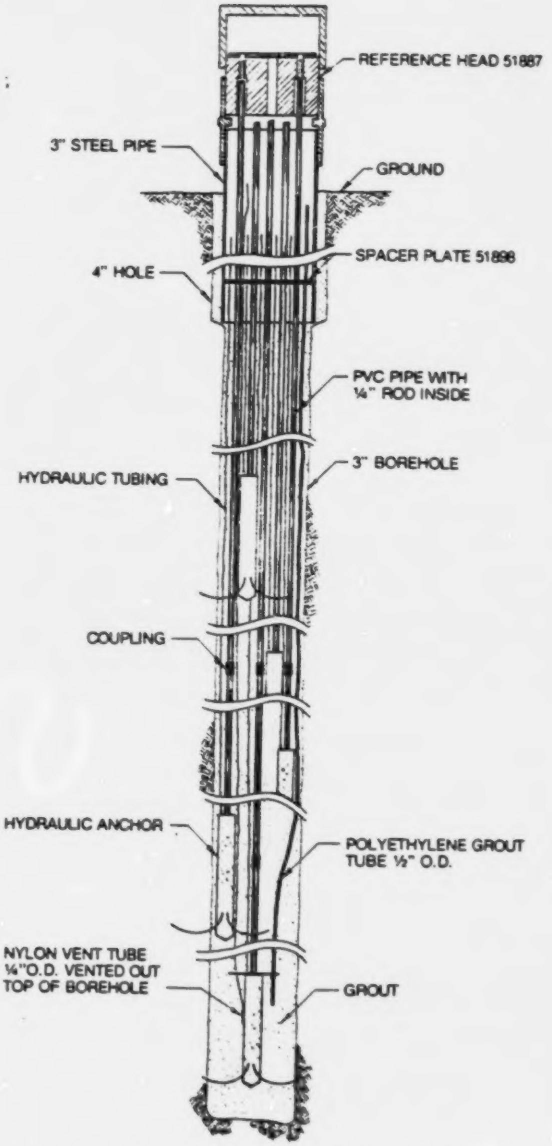

REFERENCE HEAD 51887
3" STEEL PIPE
GROUND
SPACER PLATE 51898
4" HOLE
PVC PIPE WITH ¼" ROD INSIDE
3" BOREHOLE
HYDRAULIC TUBING
COUPLING
HYDRAULIC ANCHOR
POLYETHYLENE GROUT TUBE ½" O.D.
NYLON VENT TUBE ¼"O.D. VENTED OUT TOP OF BOREHOLE
GROUT

Fig. 1 Mechanical Extensometer Installation with Hydraulic Anchors

slope indicator company SINCO

The anchor points can be either the grout-in or hydraulic type anchor. The grout-in anchor consists of a No. 6 rebar which has been drilled and tapped to mate with the rod and protective tube and is grouted in the borehole. The hydraulic anchor is expanded hydraulically to lock the prongs firmly into the wall of the borehole. The hydraulic anchor after being expanded can also be grouted in the borehole.

The reference head, with the exception of the stainless steel reference plate, is polyvinyl chloride with a maximum diameter of 4 inches including the protective cap. The reference head is mounted on a 3 inch IPS steel or plastic pipe embedded in the borehole.

Model 51891 Electrical Extensometer

An electrical sensing head, Fig. 2, can be installed in place of the stainless steel reference plate. The precision electrical sensing elements are 2 inch travel linear potentiometers mounted in a PVC housing. The potentiometer shaft is held in contact with the end of the extensometer rod by means of a compression spring.

Model 518101 Extensometer Indicator is used to monitor movements of the electrical sensors. The Indicator is a liquid crystal, battery powered Digital Readout. Remote Reading Automated Data Acquisition systems are also available.

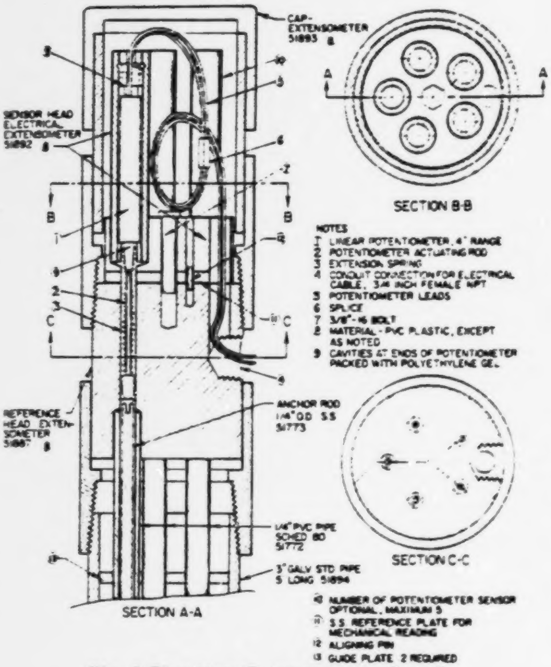
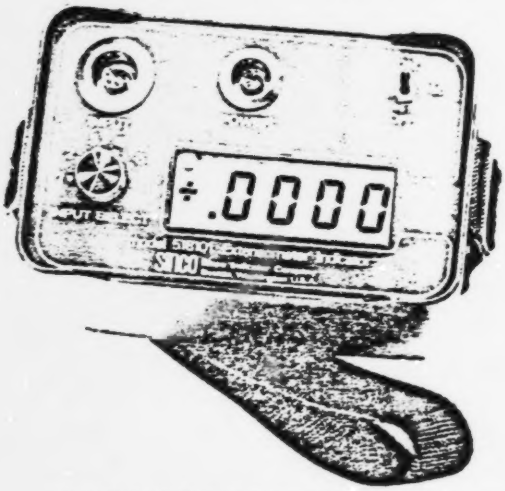

CAP-EXTENSOMETER 51893 8
SENSOR HEAD ELECTRICAL EXTENSOMETER 51892 8
REFERENCE HEAD EXTENSOMETER 51887 8
ANCHOR ROD 1/4" O.D. S.S. 51773
1/4" PVC PIPE SCHED 80 51772
3" GALV STD PIPE 5' LONG 51894
SECTION A-A
SECTION B-B
SECTION C-C
A
B
C
1
2
3
4
5
6
7
9
10
11
12
NOTES
1 LINEAR POTENTIOMETER, 4" RANGE
2 POTENTIOMETER ACTUATING ROD
3 EXTENSION SPRING
4 CONDUIT CONNECTION FOR ELECTRICAL CABLE, 3/4 INCH FEMALE NPT
5 POTENTIOMETER LEADS
6 SPLICE
7 3/8" - 16 BOLT
8 MATERIAL - PVC PLASTIC, EXCEPT AS NOTED
9 CAVITIES AT ENDS OF POTENTIOMETER PACKED WITH POLYETHYLENE GEL
10 NUMBER OF POTENTIOMETER SENSOR OPTIONAL, MAXIMUM 5
11 S.S. REFERENCE PLATE FOR MECHANICAL READING
12 ALIGNING PIN
13 GUIDE PLATE 2 REQUIRED

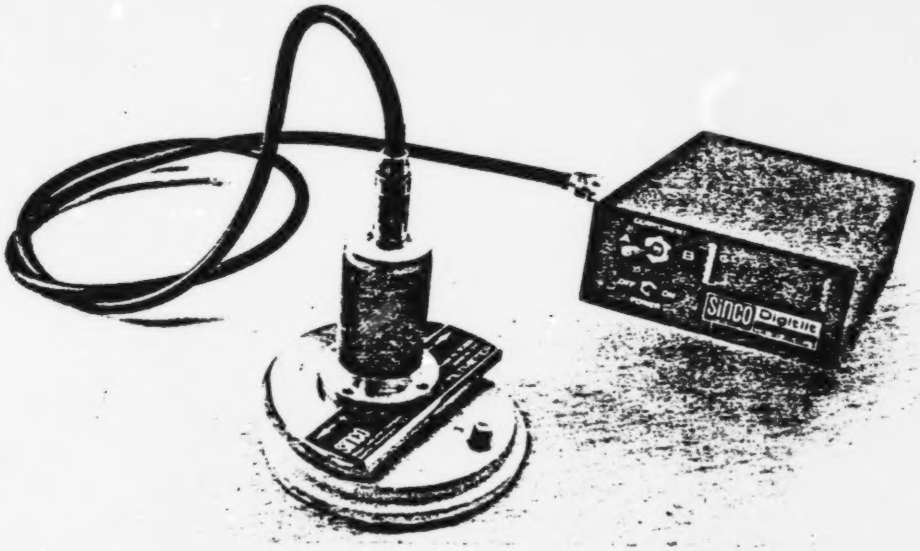
Fig. 2 Electrical Extensometer Detail



Model 518101 Extensometer Indicator

Since this is a scientific instrument, measurements should be taken, recorded and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of such personnel.

SINCO Slope Indicator Company
3668 Albion Place North, Seattle, Washington 98103 U.S.A.
TWX 910 444 2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073



Model 50306 Digitilt® Indicator with Tiltmeter Sensor (model 50322) Placed on Ceramic Tilt Plate

General Description

SINCO Digitilt® Tiltmeters are rapid-reading, precise, and portable systems designed to periodically monitor horizontal and vertical tilt of structures, soil and rock masses. These Tiltmeter Systems combine rugged, lightweight, compact, and simple operation with low cost and high accuracy.

This accuracy can be applied to measurements of: 1) tilt of rock outcrops, benches of open pit mines, highway and railway cuts; 2) surface tilt of bridge piers, retaining walls; 3) profiling of surface settlements; 4) tilt of vertical walls and structures; and 5) subsidence in landslide areas, around earth or rockfill dams, and adjacent to building excavations.

In general, the Digitilt® Tiltmeters may be used where the failure mode of a mass may be expected to contain a rotational component. Temperature-stable ceramic Tilt Plates are bonded to the surface of the mass and experience the same angular rotation. The portable Tiltmeter Sensor is placed on each ceramic plate for monitoring. Periodic measurements of the tilt plates, enable the operator to compute the rate of angular deformation.

Basic Systems

There are two basic sensors for the SINCO Digitilt® Tiltmeter. The Model 50322 measures tilt in a horizontal plane and the Model 50344 measures tilt in a Horizontal and/or Vertical plane. The system includes Ceramic Tilt Plates, a Tiltmeter Sensor, and Digitilt Indicator.

Ceramic Tilt Plate

The ceramic plates are cast from specially formulated porcelain, with four sensor orientation pegs in the upper surface. Using grout or epoxy resin, the plates are bonded to rock, concrete, or metal. They are inexpensive, durable, non-corrosive, and have high dimensional stability.

Tiltmeter Sensor

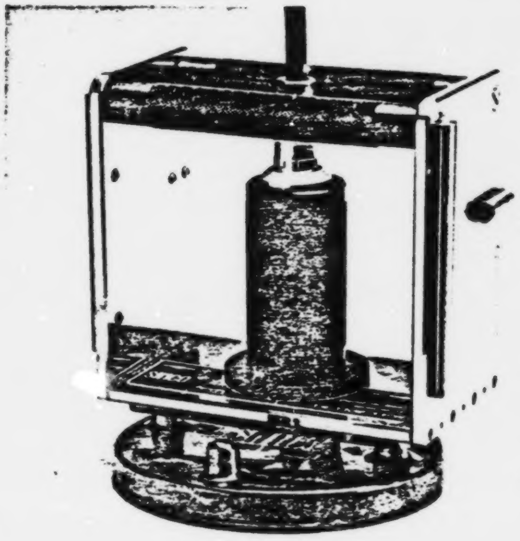
The portable tiltmeter sensor utilizes a closed-loop, force-balanced servo-accelerometer specifically designed for tilt measurements. It senses changes in tilt of the Tilt Plates. To operate, the sensor is oriented on three pegs of the Tilt Plate and an angle is read on the four-digit indicator display.

Digitilt Indicator

The standard Digitilt Indicators read 2 x sine θ over the standard operating range of ±30° from vertical on a 4 digit bi-polar digital panel meter. This allows the user to measure change in angles to ±10 seconds of arc at vertical.

The Digitilt® Indicator is powered by an internal rechargeable battery and can operate continuously for at least eight hours under normal conditions. The Tiltmeter and Indicator, because of their light weight, can be carried and operated by a one man survey team, thus reducing data costs.

All measurements should be taken, recorded, and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of such personnel.



Model 50344 Tiltmeter Sensor in Reading Position on Ceramic Tilt Plate

SPECIFICATIONS

SYSTEM

Range: ±30° from the vertical, greater or smaller ranges of inclination available on special order

Sensitivity: 1 part in 10,000 (10 seconds of arc are equivalent of 200 microinches elevation difference on the pegs)

Temp. Coef: ±.003% of Range ±.003% of reading/°F

SENSOR, MODEL 50322

Sensing Element: A closed-loop, force-balanced servo-accelerometer, mounted with sensitive axis perpendicular to the surface of the plate.

Dimensions: 6-in. (15.2 cm) diameter, semi-circular base, 3 in. (7.6 cm) high

Material: Base: Steel, chrome plated
Accelerometer Housing: Aluminum

Carrying Case (for Sensor):
Aluminum-5 in. (12.7 cm) x 7 in. (17.8 cm) x 5 in. (12.7 cm)

SENSOR, MODEL 50344

Sensing Element: Same as Model 50322

Dimensions: 6.5 in. (16.5 cm) x 3.5 in. (8.9 cm) x 5.75 in. (14.6 cm)

Material: Base: Steel, chrome plated.
Accelerometer Housing: Aluminum

Carrying Case (for Sensor):
Aluminum - 7 in. (17.8 cm) x 10 in. (25.4 cm) x 7 in. (17.8 cm)

CERAMIC TILT PLATE, MODEL 50323

Dimensions: 6-in. (15.2 cm) diameter x 3/4 in. (1.9 cm) thick; 4 pegs equally spaced 4 in. (10.2 cm) apart

Material: Specially formulated porcelain

INDICATOR, MODEL 50306

Power: Self-contained rechargeable 6V battery

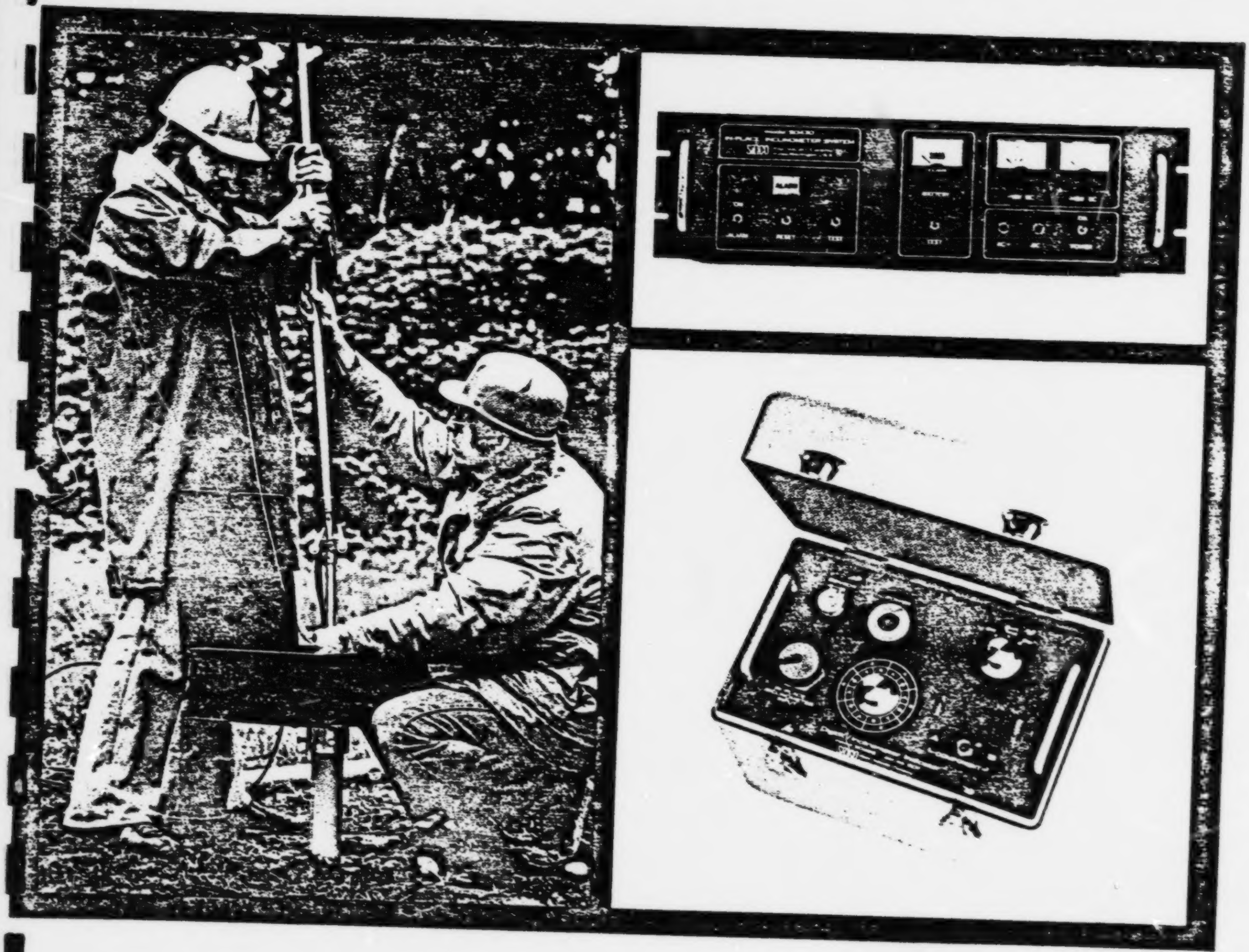
Operating Time: Approximately 8 hours fully charged

Dimensions: 5.62 in. (14.3 cm) x 2.37 in. (6 cm) x 9 in. (22.9 cm)

Weight: 5 pounds (2.3 kg)

Material: Aluminum Case

IN-PLACE INCLINOMETER


IN-PLACE INCLINOMETER SWITCH
ALARM
RESET
TEST
POWER

Sinco

slope indicator company

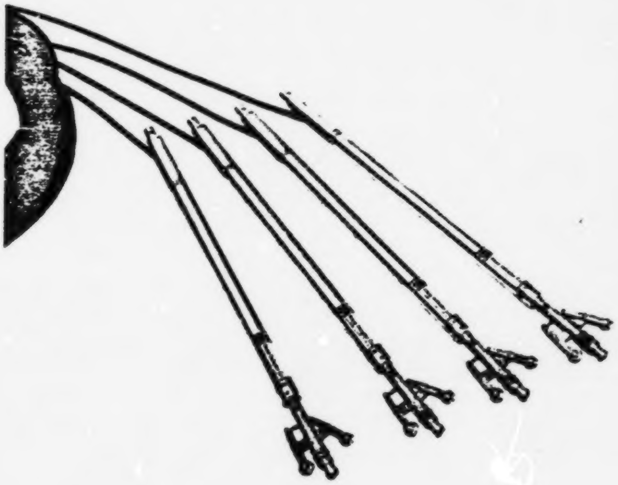
IN-PLACE INCLINOMETER

- Continuous or automatic monitoring
- Highly precise measurements
- Easy to install, operate, and recover
- Remote readout reduces engineering time
- Solid state electronics
- Rugged construction
- Automatic alarm capability

General Description

The In-Place Inclinometer is a multi-sensor displacement measuring system for installation in boreholes, which enables the engineer to monitor minute movements in landslides, dams, embankments, buildings, or open-pit mines. It supersedes the standard inclinometer in situations where frequent or continuous measurements are required.

In-Place Inclinometers can be monitored either manually or automatically. The manual system consists of one or more sensors, placed where movement is to be monitored, a readout station and portable Indicator. Automatic systems consist of one or more sensors, a junction box, power supply, and a data logger. Options include alarms and transmission of data to remote locations via telephone lines. For safety or engineering purposes, the alarm option will automatically generate an alarm when movement of any individual sensor exceeds a pre-set threshold.



Model 50432 In-Place Inclinometer Sensor Assemblies with cables attached

Sensors

The In-Place Inclinometer sensor includes one or two precision closed-loop accelerometers (two accelerometers if two axes of movement are to be measured). The lateral movement of one end of the sensor relative to the other end is measured with a resolution that is better than .001 inches over a ten-foot gauge length (.025mm over a 3 meter gauge length).

Sensor outputs can be continuously sampled, converted to a digital format, and displayed. Each measurement is completely independent of the measurement on the adjacent sensor so there is no cumulative buildup of offset or drift errors.

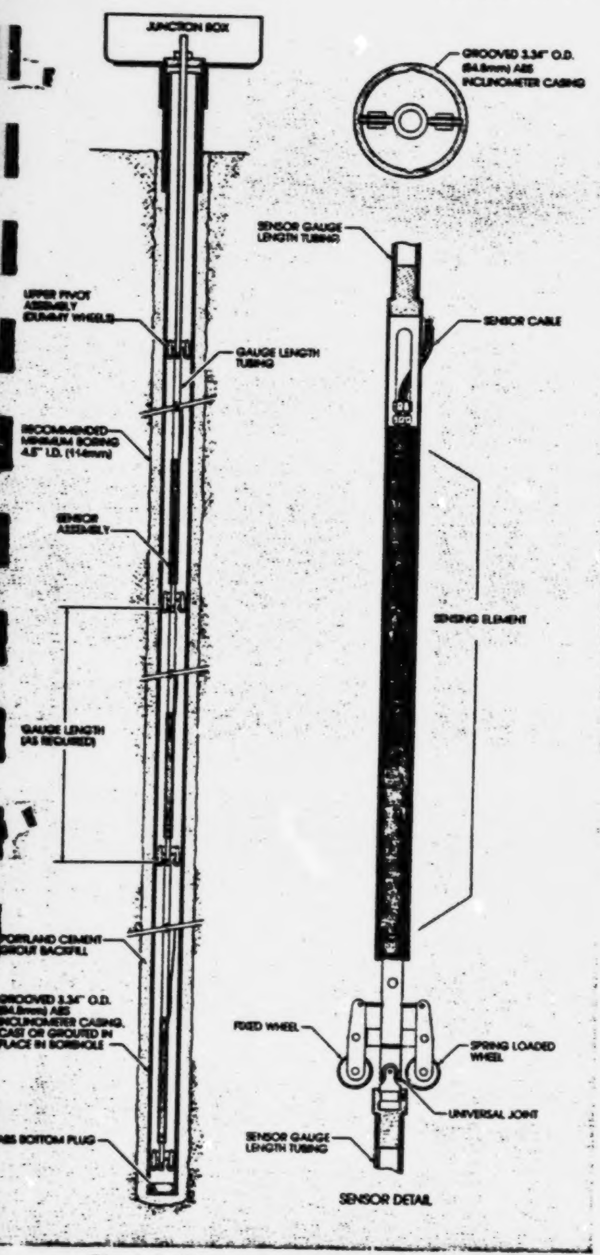

JUNCTION BOX
GROOVED 3.34" O.D. (84.8mm) ABS INCLINOMETER CASING
SENSOR GAUGE LENGTH TUBING
UPPER PIVOT ASSEMBLY (DUMMY WHEELS)
GAUGE LENGTH TUBING
SENSOR CABLE
RECOMMENDED MINIMUM BORING 4.5" I.D. (114mm)
SENSOR ASSEMBLY
SENSING ELEMENT
GAUGE LENGTH (AS REQUIRED)
PORTLAND CEMENT GROUT BACKFILL
GROOVED 3.34" O.D. (84.8mm) ABS INCLINOMETER CASING, CAST OR GROUTED IN PLACE IN BOREHOLE
FIXED WHEEL
SPRING LOADED WHEEL
UNIVERSAL JOINT
ABS BOTTOM PLUG
SENSOR GAUGE LENGTH TUBING
SENSOR DETAIL

Fig. 1. In-Place Inclinometer Installation

Guide wheels keep the sensor centered within the [illegible]andard SINCO ABS inclinometer casing. This [illegible]sing has been used successfully for 15 years in all types of environments. The sensors are connected [illegible] rigid stainless steel tubes of variable lengths. A [illegible]ecision universal joint on the bottom of each sensor housing connects to the next lower sensor [illegible]d tube assembly, allowing articulated movement. [illegible]p to 16 sensors can be installed in a single obser[illegible]tion well. A three sensor installation is shown in figure 1. The three sensors can be of varying gauge [illegible]ngth and the dummy wheel assembly can be positioned any distance below the top of the casing. Electrical cable from each sensor is brought up the casing and terminated in the weather proof junction box mounted on top of the casing. Readings can be obtained with a portable indicator at this location. The entire In-Place Inclinometer assembly may be removed for repair or salvage.

Automatic In-Place Inclinometer

The Automatic In-Place Inclinometer system with alarm option continuously monitors the status of all gauges, compares the deflection change of each gauge to a pre-set threshold, and if this deflection exceeds the threshold, generates an alarm. Provisions are included to minimize the possibility of the alarm being triggered by electrical interference or construction vibrations. The system operates from 115/230 V, 60 Hz power in a protected environment.

Up to 40 sensors can be scanned and recorded at least once every fifteen seconds with the automatic system. The deflection is displayed to a resolution of 1/1000 of an inch, with a range exceeding ±30 inches (resolution of .01mm, with a range exceeding ±300mm). Offsets can be programmed so that the initial deflection of each gauge (following installation) can be offset to zero.

Telemetry System

The automatic system can be interfaced to a telephone line via a telephone-company-provided hookup module. The telephone line and the hookup unit are leased by the client from the telephone company. The modem that formats the data for transmission over the phone lines can be provided with the equipment described here. When a call is placed from a remote data acquisition unit, the In-Place Inclinometer automatically answers the phone and begins transmitting all the information necessary to describe the status of the system. Data is transmitted repeatedly until the caller hangs up. Data transmitted will include the deflection of each gauge as well as the status of the alarm system.

Remote data acquisition units are available. These units include an acoustic adapter so they may be coupled to any standard telephone set. The data acquisition units decode the data received via the acoustic adapter or modem, and print a record of this data. The units are portable and are powered by 115 VAC 60 Hz power.

Since this is a scientific instrument, measurements should be taken, recorded, and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of the personnel used.

SPECIFICATIONS

SENSOR, 50432

Full Scale:
±30° (Inches System)
±15° (Metric System)

Resolution:
.001 in for 10-ft (.025mm for 3-m) gauge length (1.7 seconds of arc)

Hysteresis:
.001 in for 10-ft (.025mm for 3-m) gauge length

Temp. Coef:
±.002 in /°F for 10-ft (±.09mm/°C for 3-m) gauge length

Voltage Output:
12.000 x Sin Θ (Inches System)
30.00 x Sin Θ (Metric System)

Dimensions:
1 in (25.4mm) OD x 20.5 in (521mm) long

Weight:
Sensor: 2.5 lb (1.1 kg)
Tubing: .5 lb/ft (.75 kg/m)
Cable: 5 lb/100-ft (7.5 kg/100m)

Water Pressure:
150 psi (1000 KPa)

Materials:
Stainless Steel housing and tubing

Operating Temp:
0°F to 120°F (-18°C to 49°C)

PORTABLE INDICATOR, 50406

Range:
±20.000 in (9.6° for 10-ft gauge length)
(±200.00mm) (3.8° for 3-m gauge length)

Resolution:
.001 in (.01mm)

Accuracy:
±.02% of Reading, ±.01% of Range)

Temp. Coef:
±.008% Reading/°F + .0006% Range/°F
±.015% Reading/°C + .001% Range/°C

Dimensions:
11 in x 7 in x 11 in (28 cm x 17.8 cm x 28 cm)

Weight:
11 lb (5 kg)

Operating Temp:
0°F to 120°F (-18°C to 49°C)

AUTOMATIC IN-PLACE INCLINOMETER

Range:
±30.000 in (14.5° for 10-ft gauge length)
±(300.00mm) (5.7° for 3-m gauge length)

Resolution:
.001 in (.01mm)

Accuracy:
±.02% Reading, ±.01% of Range

Temp. Coef:
±.003% Reading/°F ±.0006% Range/°F
(±.005% Reading/°C ±.001% Range/°C)

Sample Rate:
3 sensors/sec.

Power:
115/230V ±10% 60 Hz (50HZ opt.) less than 125 watts

Dimensions:
7 in x 19 in x 22 in (17.8 cm x 48.3 cm x 55.9 cm)

Weight:
40 lbs (18.2 kg)

Operating Temp:
32°F to 120°F (0°C to 49°C)

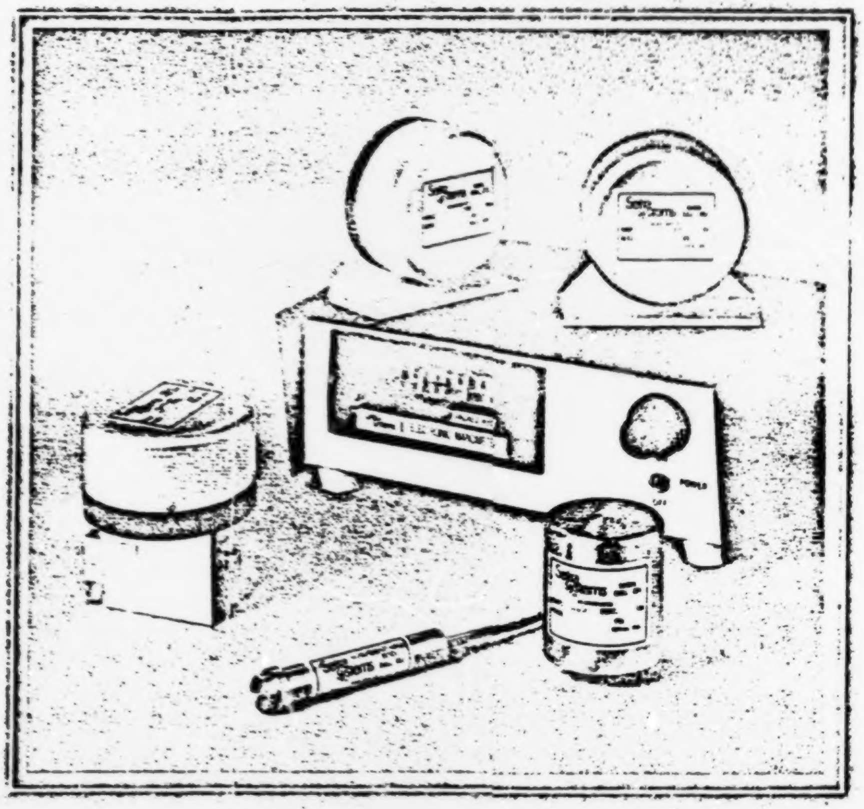
Humidity:
0 to 90%, non-condensing

SINCO
Slope Indicator Company
3668 Albion Place North, Seattle, Washington 98103 U.S.A.
TWX: 910-444-2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073

Printed in USA (3-79)

APPLICATION GUIDE

PRESSURE TRANSDUCERS AND TRANSMITTERS



Setra systems INC.

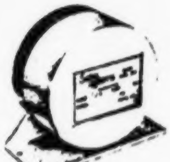
PRESSURE TRANSDUCERS & TRANSMITTERS*

0.01 to 10,000 psi

Each a Complete System with Self-Contained Electronics

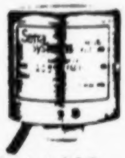
Usable with any Pressure Data System

Compatible with your Power Source, Readout, Digital Display, Microprocessor, A/D Converter, Computer, Meter, Chart or Tape Recorder

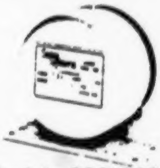


Models 204/204E
Absolute, Gage Pressure and Vacuum

Model 237
Fits Scanivalves
Absolute, Differential Pressures and Vacuum



Model 205
Gage Pressure



Models 239/239E
Absolute, Gage and Differential Pressures and Vacuum

Model 228
Low Differential Pressure at High Line Pressure (can be wet both sides)

Model 250
Setraquartz™ Sensor
Barometric Pressure, Absolute and Gage Pressures

DIGITAL DISPLAY / ANALOG OUTPUT
(BCD Output Optional)

DIGITAL PRESSURE READOUT
Model 300A - has LCD
Model 300B - has LED

- **For Panel-Mounted Display**
- **Used with one or more transducers**

Each of the transducers in this catalog may be used with either of these Setra Systems Digital Display Instruments.

DIGITAL PRESSURE INDICATOR
(Model 300C)

- **Portable, Bench-top Display**
- **Transducer cable plugs into rear panel**

ELECTRONIC MANOMETERS
(Models 304, 339, 350)

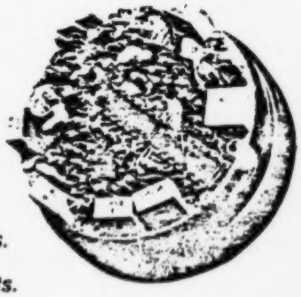
Complete system. Has transducer built-in:

Manometer	*Transducer*
304	*204*
339	*239*
350	*250*

*Setra Systems provides a complete line of *Digital Pressure Measurement Systems* and *Readout Devices*. Please request Setra Catalog DP-200.

SETRA SYSTEMS' TRANSDUCERS
feature

- ☐ **High Level Outputs**
  0 to 5 VDC. 0 to ±2.5 VDC (bidirectional)
- ☐ **Remote Zero Adjust, Remote Sensitivity Adjust and Remote Calibration Signal (optionally available)**
- ☐ **Capacitance-Type, High Accuracy Sensors**
  Stainless Steel sensors accept most pressure media
  SETRAQUARTZ™ Sensors for highest accuracy
- ☐ **Calibration Referenced to NBS Standards**



Full signal conditioning circuits in Setra pressure transducers produce high accuracy/high output measurements. Internal zero and sensitivity adjustments.

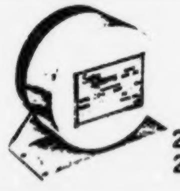
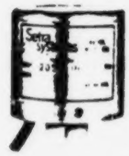
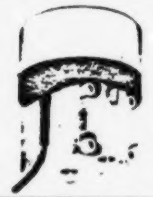
Output Impedance:	<20 ohms
Excitation:	Nominal 24 VDC (unregulated) Each transducer has its own internal regulation ±24 VDC or ±15 VDC with grounded output (optional) 12V or 10V (optional)

Ambient Operating Temperature Limits:	0 to 175°F
Compensated Temperature Range:	30°F to 150°F
Extended Temperature Range:	−65°F to 250°F available some units

HIGH OUTPUT/HIGH ACCURACY PRESSURE AND VACUUM TRANSDUCERS

All Transducers and Transmitters available on GSA.

Models 204, 228, 239 and 250 are available as 4-20 ma Pressure Transmitters for two-wire systems.

		 204 & 204E	 205	 228	Fits Scaniva
Application		Absolute Pressure Gage Pressure Vacuum	Gage Pressure	Differential Pressure [illegible]	[illegible]
Media Compatibility[2]	Pressure and Vacuum	Gas or liquid Compatible with stainless steel	Gas or liquid Compatible with stainless steel, nickel	Gas or liquid Compatible with stainless steel	Gas Comp stain
	Reference Pressure (for Differential Pressure)			Gas or liquid Compatible with stainless steel	Cl non-co
Absolute Pressure Ranges	Highest Sensitivity to	0 to 25 psia (1292 Torr)			0 t
	Highest Pressure	0 to 10,000 psia			0 t
Gage Pressure Ranges	Highest Sensitivity to	0 to 25 psig	0 to 25 psig		0 tc
	Highest Pressure	0 to 10,000 psig	0 to 500 psig		0 tc
Differential Pressure Ranges	Highest Sensitivity to			0 to 1 (or ±.5) psid	0 to 0.2
	Highest Pressure			0 to 50 (or ±25) psid	0 to 500
Vacuum Range	Highest Sensitivity to	0 to 14.7 psiv			0 tc
	Highest Vacuum				0 tc
Maximum Line Pressure (for Differential Pressure)				3000 psig[2]	3
Pressure Port		¼"-18 NPT, internal	⅛"-27 NPT, internal	⅛"-27 NPT, internal	½"dia., Fi
Response to Pressure Changes[3] (milliseconds)		1 to 5 ms	1 to 5 ms	30-50 ms	2
Accuracy %FS[4]		204: 0.11% 204E 0.11%	0.11%	0.25%	
Temperature Effects	Zero Shift ± % FS/°F	204: .004 max.[5] 204E: .03 max.[5]	.02 max.	.02 max.	.C
	Sensitivity Shift ± % FS/°F	204: .003 max. 204E: .02 max.	.015 max.	.01 max.	.

Notes:
1. Stainless Steel housing (optional)
2. See catalog sheet for detail
3. For typical application, incompressible fluid (except Model 250 which accepts gas only). Exact response time depends on pressure range and system characteristics.
4. Accuracy as RSS of non-linearity, hysteresis, repeatability.
5. Thermal zero shift 50% higher for vacuum range units.
6. Thermal zero shift double for highest sensitivity units.

Definitions: Gage F

Absolu

Vacuur

Specifications subject to change without notice

No Postage
Necessary
if Mailed in
the United States

BUSINESS REPLY CARD

FIRST CLASS PERMIT NO 55 NATICK, MA

POSTAGE WILL BE PAID BY ADDRESSEE

Setra Systems INC

One Strathmore Rd., Natick, MA 01760

Setra Systems' pressure transducers and pressure transmitters accurately measure pressure (hydraulic and pneumatic); liquids and gases; coolants, fuels, lubricants, refrigerants and most other pressure media. Pressure ranges extend from high to very low pressure for Gage, Absolute, Differential and Barometric pressures and Vacuum.

Accurate Steady-State Measurements

Setra transducers and transmitters accurately measure steady-state pressures. Note that for use in constant temperature conditions Models 204E and 239E often approach the same high accuracy as the Models 204 and 239 at considerable savings.

[illegible]

The very small pressure port volumes featured in Setra Systems' transducers and the capacitance type sensors help provide exceptionally fast, accurate measurements of rapidly changing pressures. Note that our "slowest" unit, the Model 228, for Differential pressures, reacts remarkably fast, typically 40 milliseconds for wet-to-wet usage. The widely-used model 204 responds within 1 to 5 milliseconds. (See Chart inside for typical response time of all models).

SELECTING THE RIGHT TRANSDUCER

Setra Systems pressure transducers are used in a wide range of applications including:

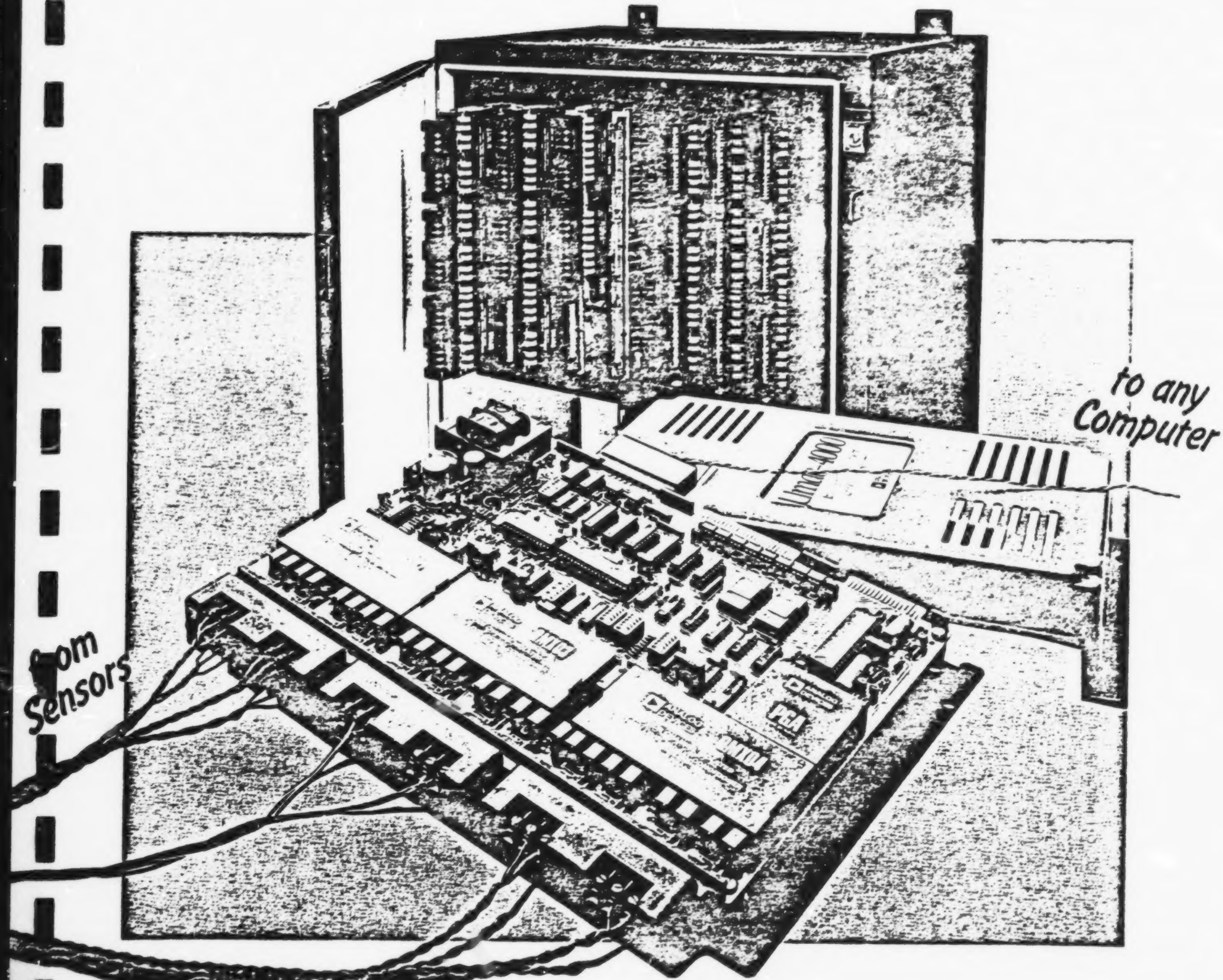
Automotive
Calibration/Transfer Standards
Engine Test Stands
Wind Tunnel
Leak Tests
Pumps, Blowers & Filter Operation
Process Monitoring
Energy/Fuel
R&D/Scientific
Environmental Systems
Flow Rates
Military
Petrochemical
Flight Tests
Oceanographic
Biomedical
Barometric
OEM Systems

The specifications in the center spread of this bulletin are oriented to help you make a preliminary selection for YOUR APPLICATION. Please contact the Setra Systems Representative nearest you, or the factory directly, for immediate assistance.

In Addition Detailed Product Bulletins with complete Performance and Engineering specifications are available for every transducer in this catalog.

μMAC-4000 The intelligent process-to-computer interface

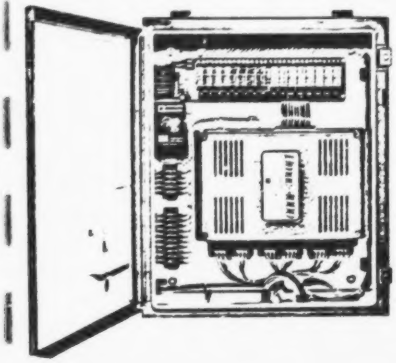
ANALOG DEVICES


to any Computer
om Sensors

μMAC-4000. The complete, low-co that's optimized for harsh

At last there's a complete, low cost solution that provides powerful measurement and control capability to virtually any computer. It's μMAC-4000—a fully integrated, intelligent system designed to monitor and control the sensors and actuators of your process under the supervision of your host computer in a wide range of industrial applications.

μMAC comes complete with sensor signal conditioning, analog and digital control outputs and built-in intelligence for distributed processing. And standard ASCII, RS-232C or 20mA communications makes interfacing to any computer fast and simple.



It's Designed for Tough Environments

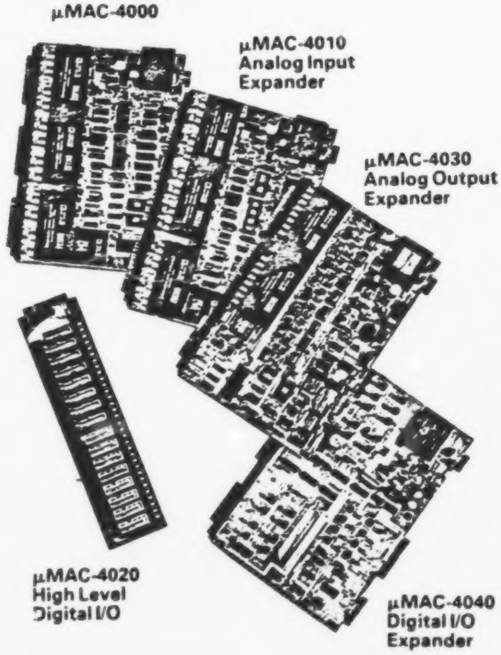
μMAC is optimized for high performance measurement and control in the harshest environments, providing ± 1000V isolation to eliminate ground loops, protect against transients and solve common mode voltage problems. Signal integrity is further preserved by an excellent common mode and normal mode noise rejection and high immunity to electromagnetic fields and RFI.

Capable of operating at temperatures up to 60°C and designed to withstand high humidity and vibration, μMAC is ideal for factory floor locations. And several packaging options, from single board enclosure to rugged NEMA cabinets, add installation flexibility to match the environment.

It's Flexible

μMAC can be easily tailored to fit your specific needs. Its unique single board design makes μMAC-4000 the most cost effective solution for small point counts, yet with its family of economical analog and digital I/O boards, μMAC-4010 through μMAC-4040, it's versatile enough to expand for any growing needs.

To further enhance flexibility in matching your application, you can choose from a family of packaged signal conditioning modules designed to allow you direct interface to the various process sensors or actuators. These modules simply plug onto I/O boards in any configuration you need. You can mix and match temperature, pressure, 4-20mA signals or analog voltage as you require, and then change as your needs change.


μMAC-4000
μMAC-4010 Analog Input Expander
μMAC-4030 Analog Output Expander
μMAC-4020 High Level Digital I/O
μMAC-4040 Digital I/O Expander

It's Easy to Use

μMAC system comes precalibrated and ready to run. All signal conditioning is already done with cold junction compensation provided for thermocouples and excitation for RTDs, and the input data scaled, linearized and converted to engineering units. You simply connect your sensors and actuators directly to the μMAC via industrial screw terminals, then connect serial interface to your computer, connect power line and go!

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output

It Assures Precise Control

μMAC's versatile output options allow you to select control output signals to best meet your specific application. You can choose from digital, voltage or current outputs to interface solenoids, annunciators, motors, valve positioners or proportional controllers.

Analog outputs feature 12-bit resolution and are available as voltage or 4-20mA/0-20mA current signals. Process current outputs offer integral loop power and ± 1000V galvanic isolation assuring the ulti-

neasurement and control system
ndustrial environments.

ιMAC's powerful command set
ASCII–based protocol can be
l w th any computer, whether
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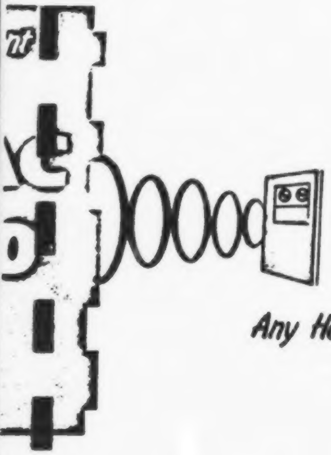

e in reliable operation through
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For eal-world control applica-
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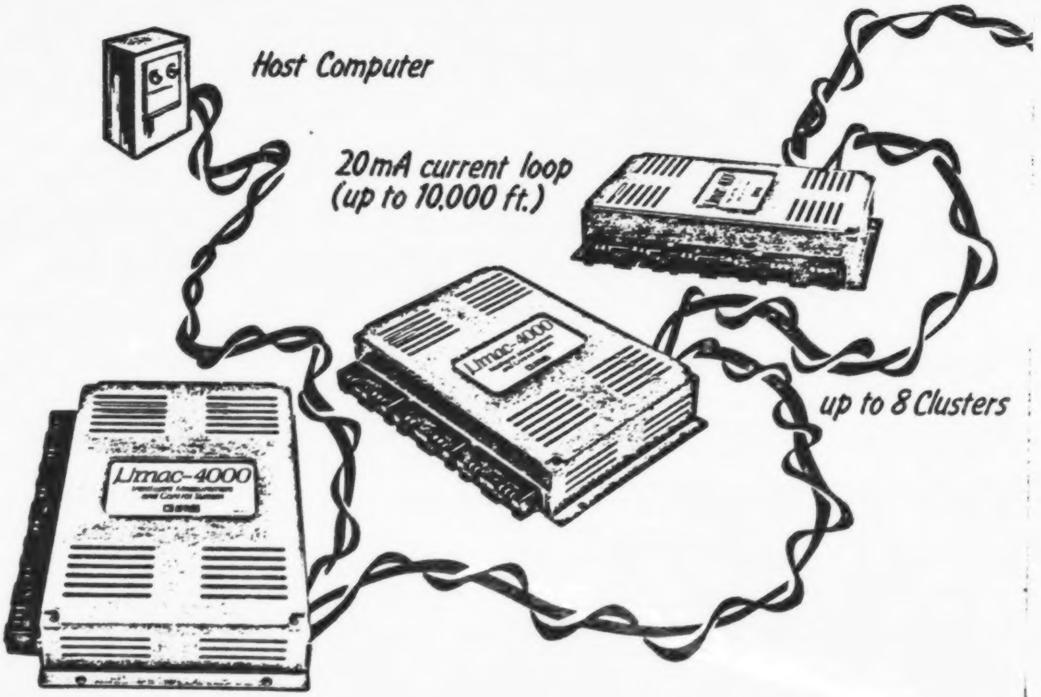


It's Reliable

μMAC-4000 combines high performance with high reliability. Through state-of-the-art design and uncompromising testing, the μMAC assures maximum reliability under continuous operation.

μMAC's reliable, transformer—isolated analog input multiplexers offer you much higher isolation voltage and much greater reliability than electromechanical relay multiplexers, no matter how tough the environment. To further enhance dependability, the μMAC-4000 meets IEEE 472-1974 surge withstand specs and offers 130V rms normal mode input protection.

Factory burn-in eliminates component infant mortality problems, and surge protection on power inputs guards against damage from line transients.

It Makes Remote I/O Cost Effective

Because μMAC is built to operate in harsh plant floor environments, it makes remote I/O an easy and cost effective alternative. Now you can truly distribute the measurement and control function to improve performance, reduce costs and simplify system interface.

μMAC's serial link allows use of inexpensive twisted pair cable in either party line (multidrop) or radial (point-to-point) system configuration. A network using up to 8 clusters in a multidrop configuration allows your computer to monitor and control 640 analog and 2176 digital points over distances up to 10,000 ft. (3048m), resulting in a substantial wiring and installation cost reduction. And digital communication ensures measurement integrity over long distances—you don't have to worry about effects of line drops or electrical noise.

μMAC-4000 System Specifications

INPUT/OUTPUT

Analog Inputs
Thermocouples: J, K, T, S
RTDs: 100Ω Platinum
Solid State Temperature Sensors:
AD590 or AC2626
Strain Gage Transducers:
±30mV and ±100mV spans
DC Voltage: ±25mV, ±50mV,
±100mV, ±1V, ±5V, ±10V
DC Current: 4 to 20mA,
0 to ±1mA, 0 to ±20mA
Common Mode Voltage: ±1000V pk
(chan/chan/gnd)—isolated input modules
Input Protection: 130V rms continuous, IEEE-472 (SWC) transient
A/D Converter: 13-Bit Dual Slope
Scan Rate: 15 or 30 chan/sec

Analog Outputs
Voltage: ±5V, ±10V, 0 to +5V,
0 to +10V
Current: 4 to 20mA, 0 to 20mA
Resolution: 12-Bits
Isolation: ±1000V pk (chan/chan/gnd)—current outputs
Output Protection: 130V rms

Digital Inputs
Compatibility: TTL signals or
contact closures and μMAC-4020
for high level inputs
Isolation: ±300V pk

Digital Outputs
Compatibility: TTL signals and
μMAC-4020 for high level outputs

Channel Capacity per Board
μMAC-4000 and μMAC-4010
12 Analog Inputs
8 Digital Inputs
8 Digital Outputs
μMAC-4030
8 Analog Outputs
μMAC-4040
32 Digital Inputs
32 Digital Outputs
μMAC-4020
16 High Level Digital Inputs and Outputs

Capacity per Cluster
48 Analog Inputs
32 Analog Outputs
136 Digital Inputs
136 Digital Outputs

Total System Capacity
8 addressable clusters on
one serial communication port

COMMUNICATIONS

Mode: 4 wire full duplex
20mA current loop or RS-232C
Format: Serial Asynchronous ASCII
Rate: Selectable from 110 to 9600 baud
Distance: RS-232C; 50 ft (15m)
20mA, 10,000 ft (3048m)
Protocol: Command/Reply (prompted)

POWER

100/115/220/240V ac, 50/60Hz
or +24V dc

MECHANICAL

Single Board: 9.5" × 13"
(241.3 × 330.2mm)
4-Slot Card Cage: 14.8" × 11.2" × 10.3"
(376.0 × 284.5 × 261.6mm)
7-Slot Card Cage: 15.75" × 19" × 11"
(400.0 × 482.6 × 279.4mm)

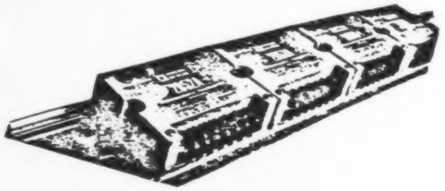
ENVIRONMENTAL

Operating Temperature: 0 to +60°C
Humidity: meets MIL-STD 202, Method 103
Vibration: meets MIL-STD 167-1
Magnetic Field Immunity: 200 gauss
RFI Immunity: 5W @ 27MHz @ 3 ft

Other Industrial Measurement and Control Products from Analog Devices

Analog Devices, the world leader in precision measurement and control, offers a broad line of products, including a MACSYM family of complete measurement and control systems and a family of two-wire transmitters. Our low cost transmitters, suitable for harsh industrial environments, are designed to convert sensor signals to 4-20mA at the point of measurement.

We offer ±0.1% accurate two-wire transmitter models for thermocouples, RTDs and AD590, as well as loop powered isolators.



Service and Support Worldwide

Analog Devices provides comprehensive service and product support through direct sales and service offices across the United States and through subsidiary offices and sales representatives around the world. That service includes installation, field service hot line, as well as application engineering assistance to insure that the system is running quickly and smoothly. And our systems are thoroughly documented for ease of operation and maintenance by in-depth data sheets, operating manuals and other product literature.

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Analog Devices, Inc., Box 280, Norwood, Ma 02062; Headquarters: (617) 329-4700; California: (714) 842-1717, (408) 947-0633; Illinois: (312) 653-5000; Michigan: (313) 644-1866; New Jersey: (201) 967-1126; Ohio: (614) 764-8795, (216) 531-9455; Pennsylvania: (215) 643-7790; Texas: (214) 231-5094, (713) 664-6704; Washington (206) 251-9550; Belgium: 031/37 48 03; Denmark: 02/84 58 00; France: 01/687 34 11; Holland: 016/20 51080; Israel: 052/28995; Italy: 02/68 98 045; Japan: 03/263 6826; Sweden: 08 282740; Switzerland: 022 31 57 60; United Kingdom: 01/941 0466; West Germany: 089-514010; and representatives around the world

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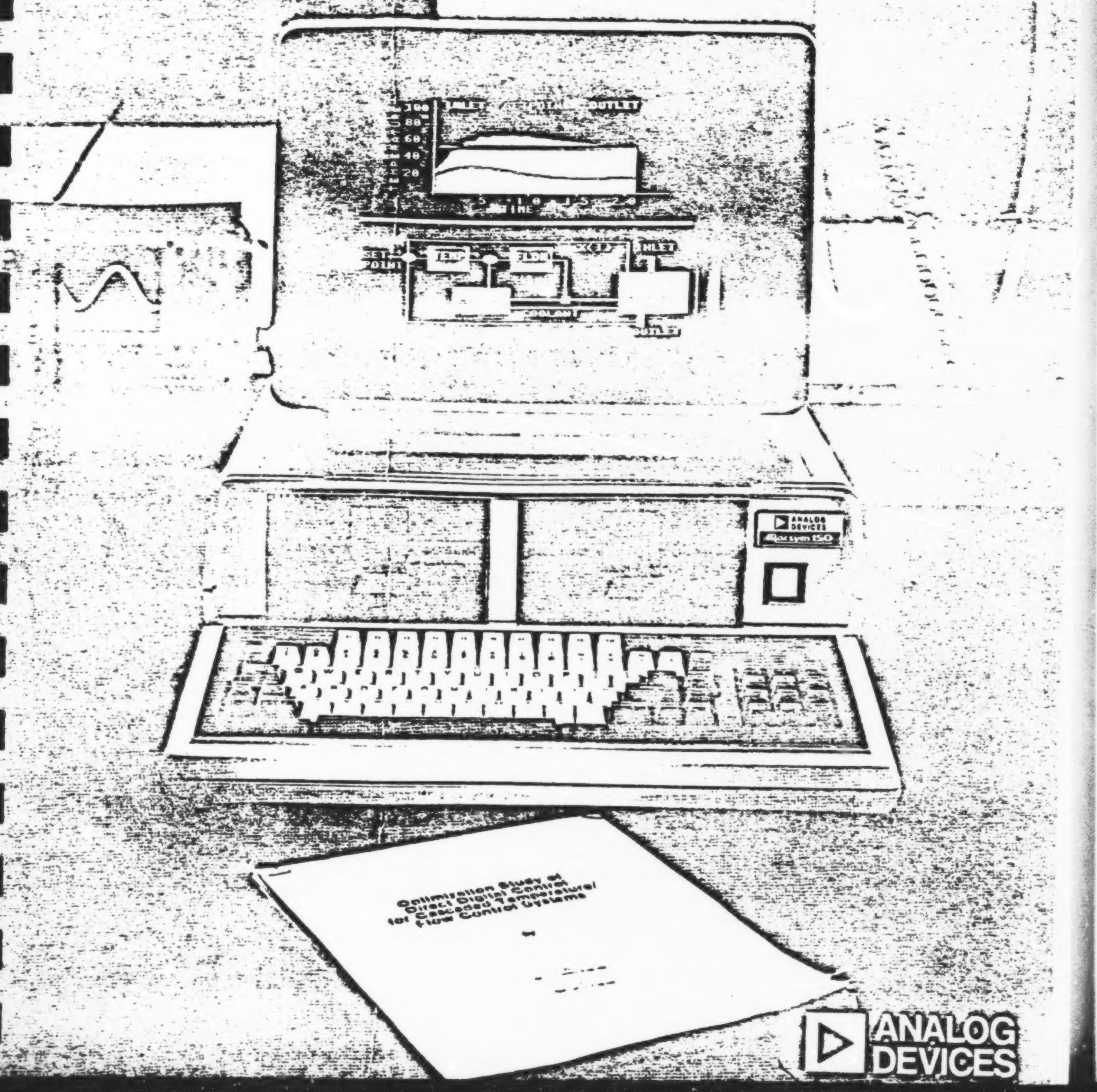
G699-30-3/82

The 16-bit MACSYM 150.
It's the most cost effective way to handle your readings, writing and arithmetic.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TEMPERATURE
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COOLANT
OUTLET
ANALOG DEVICES
Macsym 150
Optimization Study of Direct Digital Control for Cascaded Temperature/ Flow Control Systems

ANALOG DEVICES

Introducing the MACSYM 150. A Measurement And Control SYsteM that's equally comfortable with professional computing.

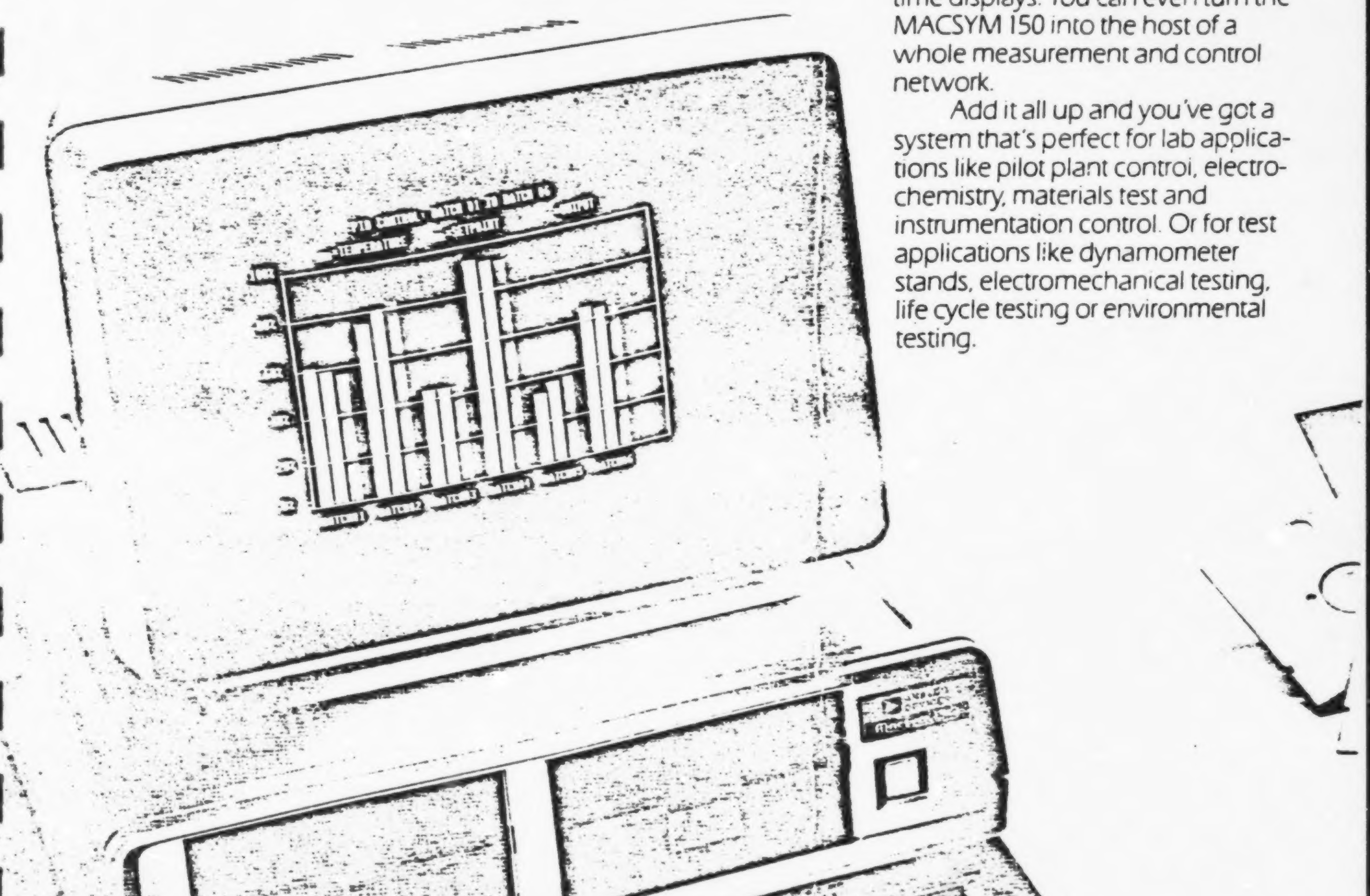
Unlike other systems, the MACSYM 150 was primarily designed as a measurement and control system, so it's totally optimized for the job.

For starters, it combines Intel's famous 8086 and 8087 coprocessor with our own unique MACBASIC 3 (Measurement And Control BASIC) software. That gives you the speed you need for real-time applications, all the user friendly aspects of the BASIC programming language, plus powerful multitasking capabilities to handle large numbers of processes concurrently.

The MACSYM 150 also incorporates 6 I/O slots integrated right into the chassis. You simply plug in the I/O cards you need and connect them directly to your sensors. No costly boxes to buy, no complicated wiring to do.

If you like, you can add optional RAM boards and expand main memory to 1 MByte. Or add color graphics for easy-to-read real-time displays. You can even turn the MACSYM 150 into the host of a whole measurement and control network.

Add it all up and you've got a system that's perfect for lab applications like pilot plant control, electrochemistry, materials test and instrumentation control. Or for test applications like dynamometer stands, electromechanical testing, life cycle testing or environmental testing.



The only
and control system that becomes

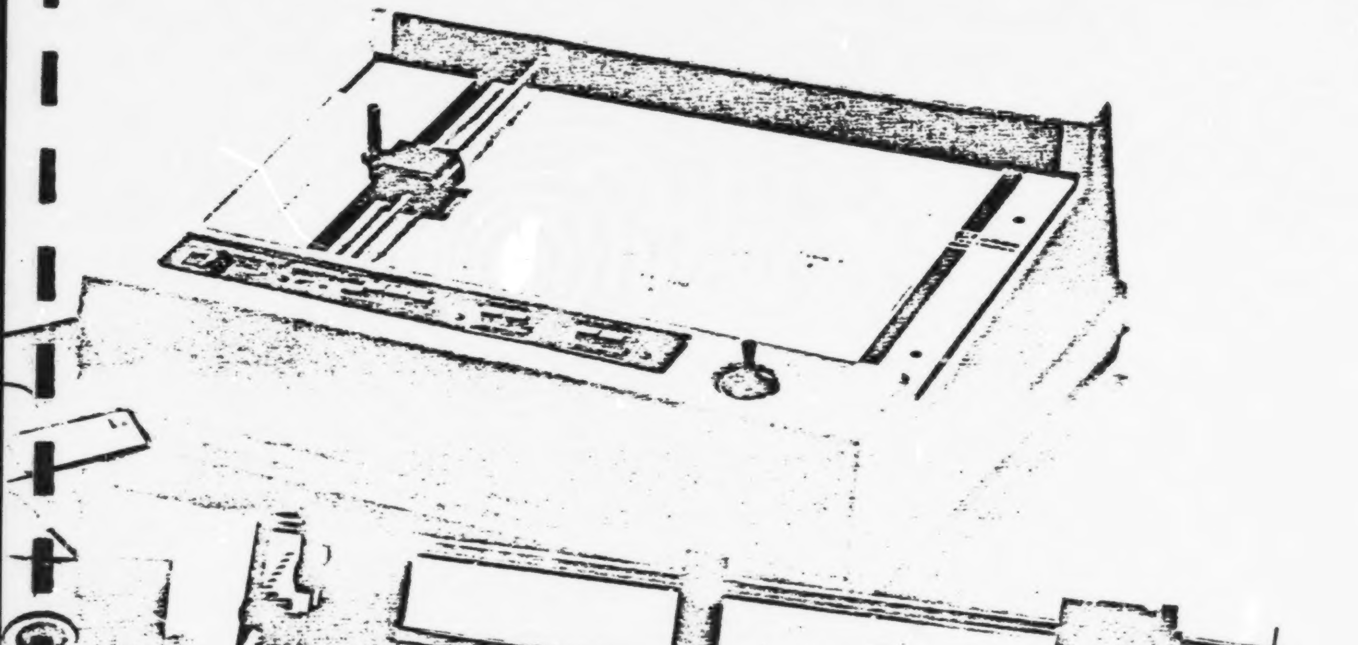
CP/M Software. Packages for everything from data reduction to word processing.

The real beauty of the MACSYM 150 is its operating system. Based on MP/M-86®, a multitasking superset of CP/M-86®, it lets you choose from a huge library of prepackaged software application programs available from a wide variety of third party sources.

By simply swapping floppy disks, you can use your MACSYM 150 for just about anything you like. Data reduction. Report generation. Financial modelling. Statistical analysis. Word processing and more.

You can even add accounting packages to help keep track of your department's budget.

In short, anything a personal computer can do, the MACSYM 150 can do.



measurement
d 16 bit workstation.

ANALOG DEVICES

® MP/M-86 and CP/M-86 are registered trademarks of Digital Research Corporation.

Despite its low price, the MACSYM 150 is far faster and far more efficient than any system in its price range.

That's because it's based on Intel's powerful 8086, the most widely used 16 bit microprocessor in the world. For even more speed, the 8086 works in tandem with Intel's 8087 math coprocessor. Instead of tying up the 8086 CPU with arithmetic (+, −, ×, ÷) or transcendental (sin, cos, log, etc.) functions, the MACSYM 150 shifts math calculations to the 8087 hardware. So it can process data up to 100 times faster than single processor systems.

And the performance doesn't stop there. The MACSYM 150 gives you an intelligent DMA floppy disk controller with a 5¼", 320 KByte drive as standard equipment. Plus options like dual floppy drives, for twice the storage. Or a Winchester hard disk for even more. Like extra RAM boards that let you increase main memory to a full megabyte. And our I/O cards that let you tailor the system to your applications. RS-232/422/20mA and IEEE-488 cards for communications. Analog input cards that connect directly to millivolt or voltage sources, bi-directional 12 bit analog outputs, and digital inputs and outputs for sensing and controlling on-off devices.

Multitasking. For added flexibility.

The MACSYM 150 also gives you one critical feature you won't find on most other systems.

Multitasking.

Basically, multitasking allows you to program and control individual tasks independently, and run them according to any schedule you desire. Since you have independent control over each task, you can shut down one without affecting the others. Less sophisticated systems without multitasking require you to shut down your entire system to change one loop.

Multitasking also simplifies programming and allows you to bring one task on line at a time for easier de-bugging. It permits you to prioritize processes for faster reactions in critical situations. And lets you process more information from more channels with less processing power.

For real-time applications like yours, multitasking isn't just a luxury. It's a necessity.

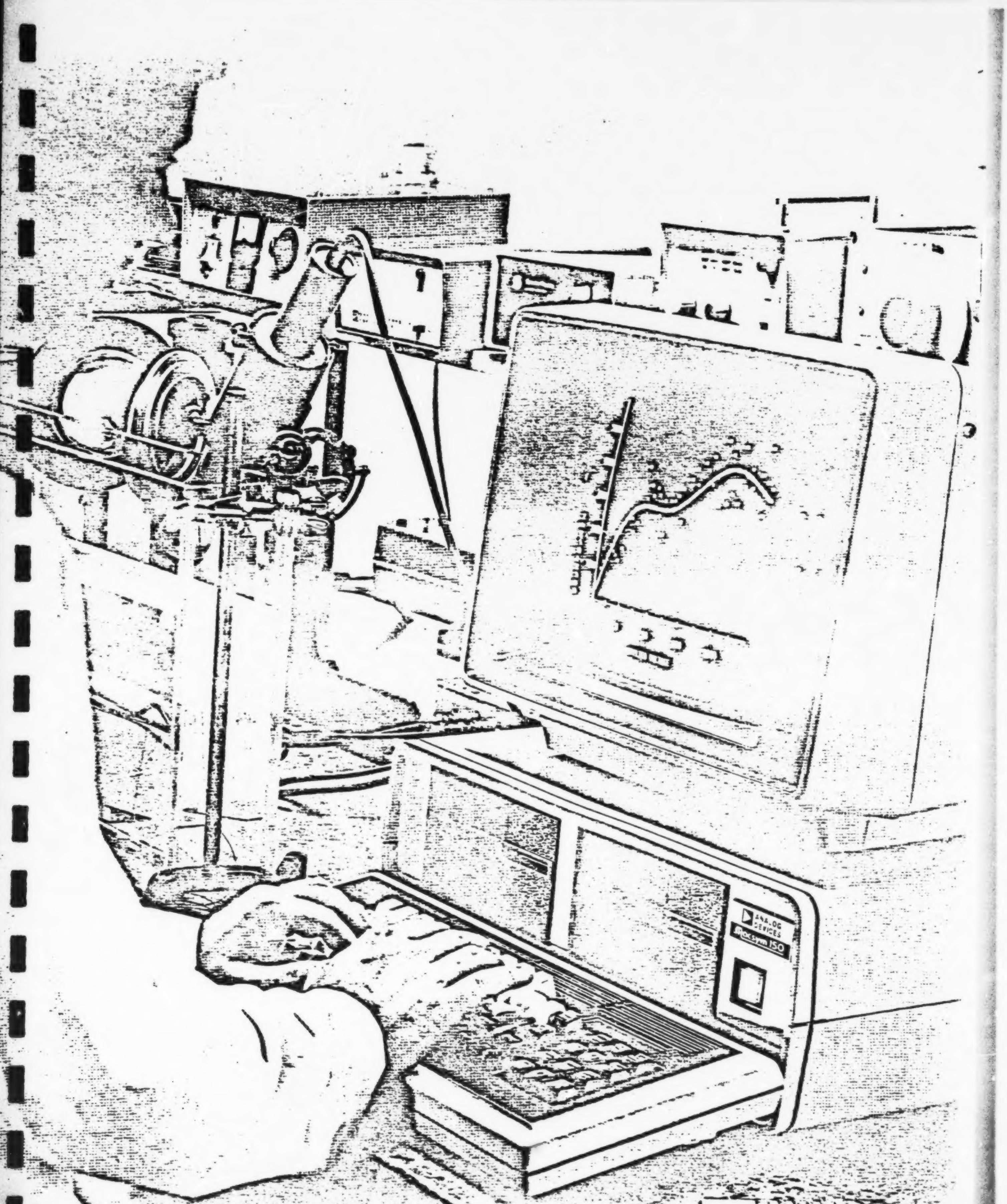
Real-time color graphics for easy-to-read presentations.

Whether you're working in the laboratory or in manufacturing, you'll really appreciate the convenience of having graphics. Black and white graphics are included in the MACSYM 150's standard configuration. But for dramatic presentations, you may want our 8 color graphics option.

Either version gives you extraordinary performance. An intelligent graphics controller off loads the 8086, allowing the system to retain full performance with graphics in use. 640 × 240 pixel raster graphics gives high resolution and animation. And simplified MACBASIC 3 commands let you generate graphics quickly and easily.

No other system in its price range gives you the speed and resolution of the MACSYM 150's graphics.

For the price of a personal computer, you get the power of a mini.


ANALOG DEVICES
Macsym 150

ANALOG DEVICES

The simplicity of an interpreter. The speed of a compiler.
Typically, most BASIC languages are slow, interpreted languages that are not very well suited for data acquisition or control. But our enhanced version, called MACBASIC 3, compiles programs incrementally, line by line as they are entered. So even though it's as easy to use as BASIC, it's much faster, with the execution speed of a compiled language like FORTRAN, PASCAL or PL/1.

MACBASIC 3 speaks your language. Plain English.
For all its extra speed, MACBASIC 3 still uses common English language commands. So even a person with little or no experience can perform calculations, address I/O cards and manipulate data quickly and easily.

MACBASIC 3 even provides special variable names and commands that further simplify its use both for measurement and control and for generating graphics. Instead of programming a long string of characters every time you use a specialized function, you simply enter a few keystrokes.

```
100  K=0.7  L=5.3  T=1      Initialize parameters.
110  X = AIN #(5,0)         Read the analog input (AIN)
                            from card slot 5, channel 0.
120  AOT #(4,0) = K*X       Set the analog output (AOT)
                            of card slot 4 channel 0
                            to 0.7 times the input value.
130  IF X>L PRINT "ALARM"   If X is greater
                            than 5.3 volts,
                            print an alarm
                            message.
140  WAIT T                 Wait 1 second
150  GO TO 110              Repeat the program
```

MACBASIC 3. An enhanced language for real-time speed.

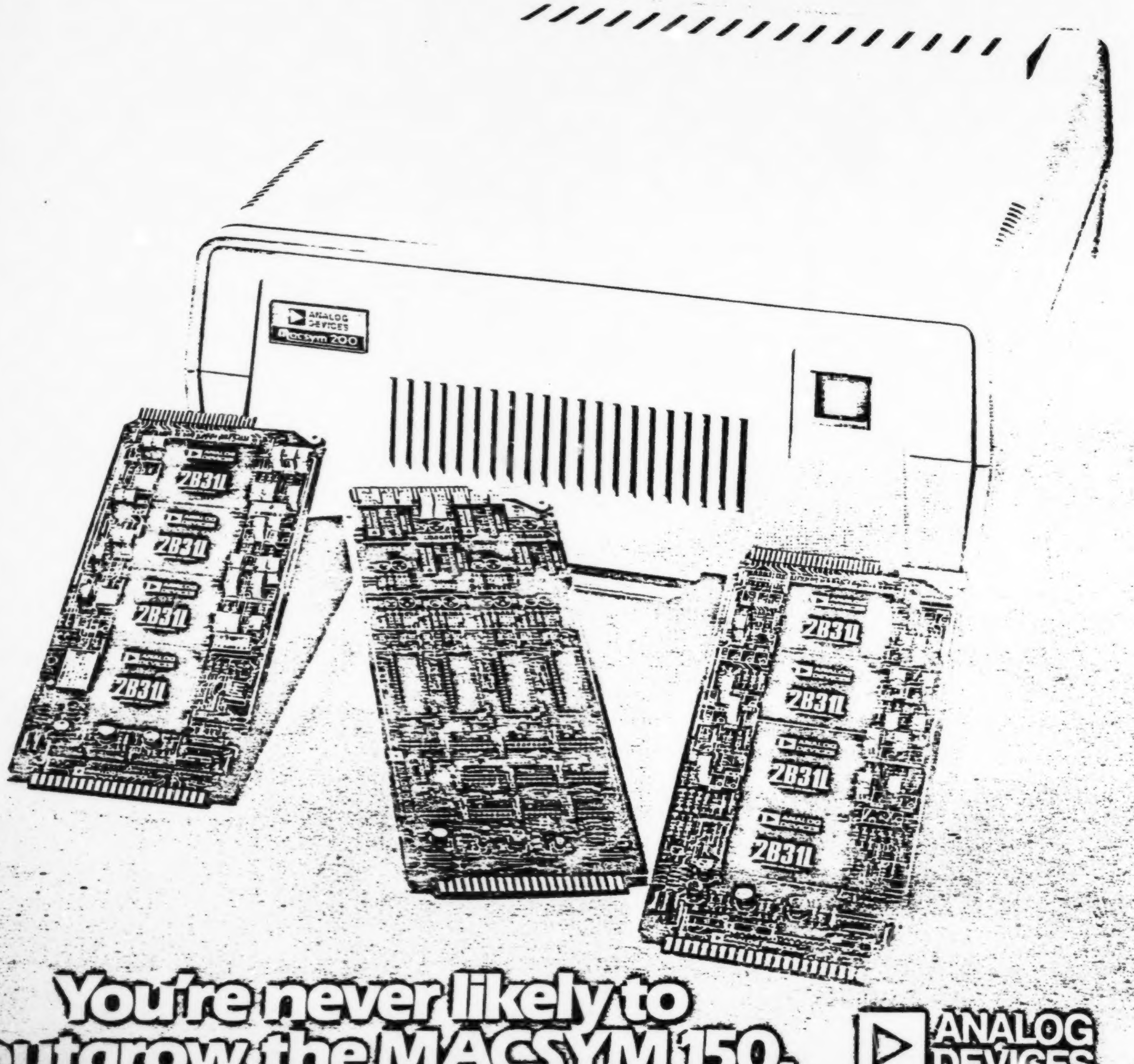
For future expansion, we've designed the MACSYM 150 so it can grow to meet your changing needs. No matter how demanding they might become.

Down the road, for instance, you might need to add more channels. Or different kinds of signal conditioning. Or perhaps you'll need faster sampling rates.

By simply adding a MACSYM 200, our intelligent measurement and control front end, you can solve all these problems. Each MACSYM 200 you add gives you an additional 16 I/O slots and lets you choose from our library of more than 30 I/O cards. The MACSYM 200 also increases your sampling rate to 33,000 samples per second burst mode, and provides local RAM for data storage.

MACNET, our 1 MBaud local area network, gives you even more capabilities for expansion. With it, you can link as many as 31 MACSYM 200's to your MACSYM 150. Also printers, plotters or any other RS-232/422 device you like.

So no matter where you go in the future, the MACSYM 150 can grow with you.



SYSTEM SPECIFICATIONS

CPU

Processor: 16 bit Intel 8086 CPU.

High speed mathematics coprocessor: Intel 8087 for arithmetic and transcendental functions.

Processor clock: 5MHz.

CAPACITY

RAM: 128 KBytes standard. Optional expansion to 1 MByte. Hamming code error correction circuitry optional.

Disk Drives: Single 5¼" floppy disk with 320 KBytes formatted standard. Dual drive optional.

DISPLAY

CRT: 12 inch screen, green phosphor standard. RGB color optional.

Text mode:
24 × 80 characters
Full ASCII character set
Blinking, underline, reverse video
Graphic character set

Graphics:
640 × 240 pixels B&W standard
640 × 240 pixels, 8 colors, optional

I/O OPTIONS

Communications:
RS-232/422/20mA
IEEE 488: Controller, Talker, or Listener

Analog Input:
Ranges from ±100 mV FS to ±10V FS, 12 bits
16 differential or 32 single-ended channels

Analog Output:
−10V to +10V FS,
12 bits, 4 or 8 channels

Digital Input/Output:
16 channels, TTL or isolated AC or DC
Switches up to:
280 VAC input or output
32 VDC input
200 VDC output

PHYSICAL SPECIFICATIONS

Electrical:
95-130 VAC or 190-260 VAC, 50/60Hz, 300 watts

Environmental:
0-35°C, 0-90% RH, noncondensing

A proven track record for service.

With direct sales and service offices around the globe, Analog Devices can give you truly worldwide support for your system. That includes installation, full documentation, a field service hotline, our user's newsletter, application notes, customer training and ongoing applications support. So no matter where you are or what you need, we're there to help.

Build on our experience in computer aided Measurement and Control.

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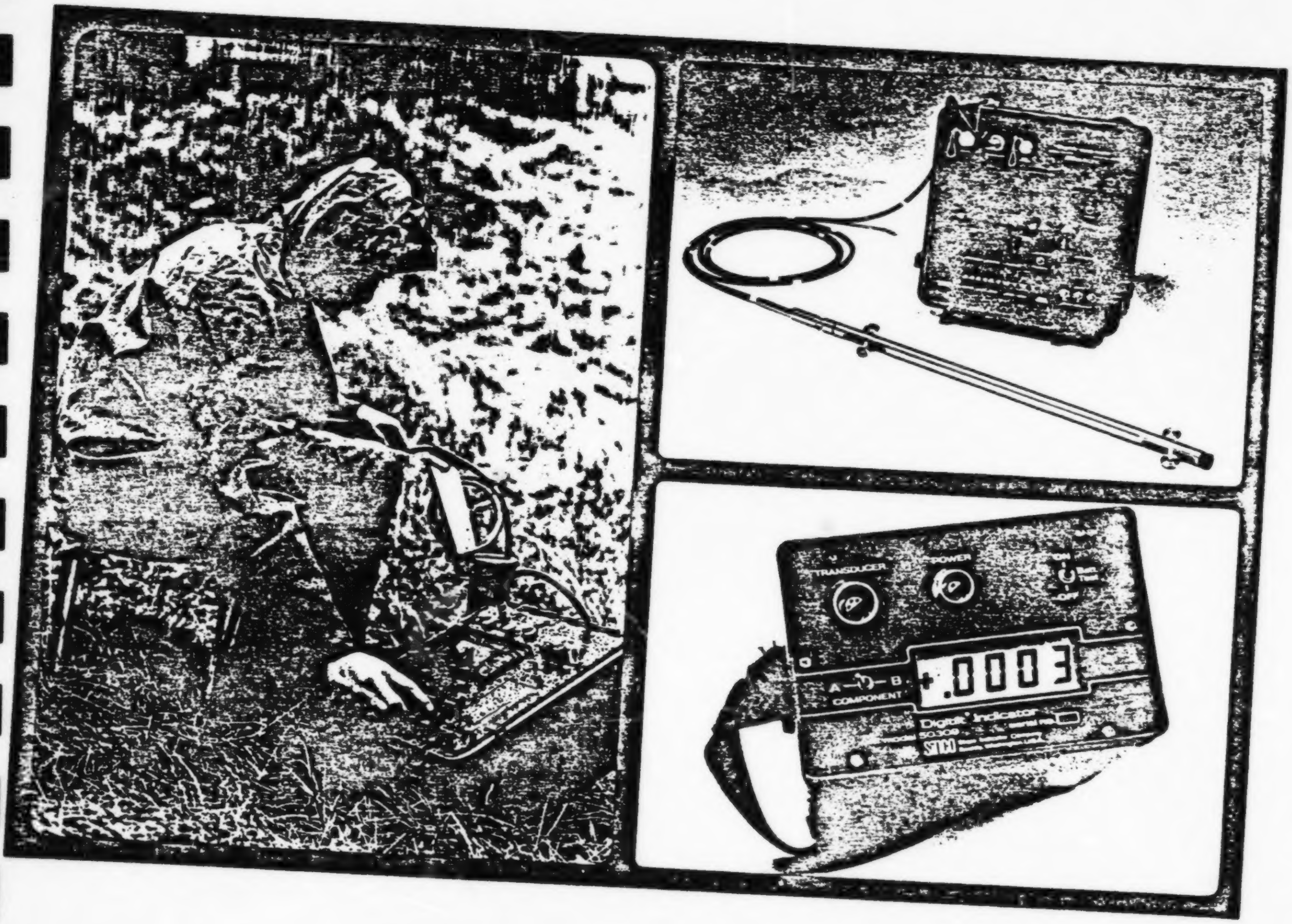
DEVICES

Measurement & Control Products
Headquarters (617) 329-4700 California (714) 842-1717 (408) 947-0633 Colorado (303) 320-6076 Illinois (312) 653-5000 Maryland (301) 992-1994 Michigan (313) 644-1866 New Jersey (201) 967-1126 New York (716) 634-7970 Ohio (614) 764-8870 (216) 531-9455 Pennsylvania (215) [illegible] Texas (214) 231-5094 (713) 664-5866 Belgium 32 3 237 48 03 Denmark 02/84 58 00 France 01/687 34 11 Holland 016 20 51080 Israel 052 28995 Italy 02 68 98 045 Japan 03 263 6826 Sweden 08/282740 Switzerland 022/3157 60 United Kingdom 01 941 0466 West Germany 089 514010

DIGITILT®
INCLINOMETER

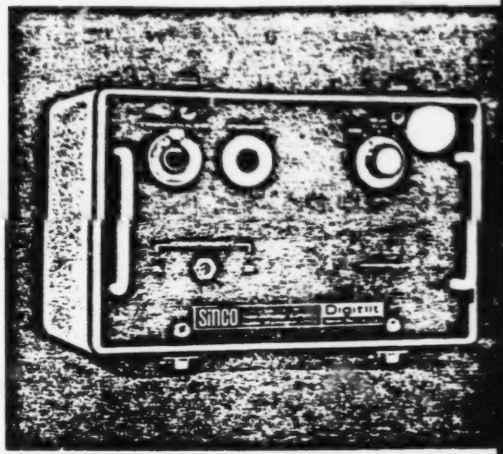

TRANSDUCER
POWER
A — B
COMPONENT
+.0003
Digitilt Indicator
SINCO

SINCO

slope indicator company

DIGITILT® Inclinometer

- Sensitivity of one part in 10,000
- Field-proven reliability
- Easy to operate
- Reads out directly in displacement
- Can be used in small diameter boreholes
- Automatic recording capability



Knowing both rate and location of lateral earth movement is critical to evaluating the performance and safety of structures and natural slopes. The Digitilt® Inclinometer System is used to measure these critical lateral movements in dams, embankments, slopes and landslides. The system has been used to monitor movement at numerous sites throughout the world ranging from Tarbela Dam in Pakistan, Mica Dam in British Columbia, China Steel Mills in Taiwan, to Climax Molybdenum in Colorado.

To determine subsurface lateral movements, grooved casing is installed in a borehole to a depth below the anticipated zone of movement. The grooves control the orientation (direction) of the sensor which is lowered through the casing to obtain initial readings at specified depths (at two foot intervals, for example). Periodic readings at these depths then provide data on the location, magnitude, direction and rate of movement of the casing.

The Digitilt® System is designed to provide overall sensitivity of ±.0001 foot lateral movement per two feet of casing or ±.02mm lateral movement per 500mm of casing. Using Slope Indicator Company casing, properly installed and within 1° (.018 rad) of vertical, the Digitilt® total system accuracy is .10 inch per 100 feet (2mm per 25 meters) of casing. For casing installation within 3° (.053 rad) of vertical, the accuracy is .3 inch per 100 feet (6mm per 25 meters).

Sensors

The biaxial sensors Models 50320 and 50325 have two servo-accelerometers in a waterproof housing. One accelerometer has its sensing axis in the plane of the spring-loaded wheels which ride in the casing grooves. The second accelerometer has its sensing axis at 90° ($\pi/2$ rad), so that the angle of inclination of sensor and casing is measured in the two orthogonal directions (both north-south and east-west components are measured).

The accelerometers are force balanced, servo type and provide a rapid stabilized response to tilt by changing the current flow through the restoring coil. The resulting voltage output is proportional to the sine of the angle of inclination of the long axis of the sensor from the vertical. The voltage is positive for positive angles of inclination and negative for negative angles. The output voltage is stable with respect to temperature, cable resistance and input voltage variations. The standard Digitilt® System will operate through ±30° ($\pi/6$ rad) from the vertical. Using optional 1.0g accelerometers, this range may be expanded to ±90° ($\pi/2$ rad). The metric Digitilt® system will operate through ±23° (.40 rad) from the vertical (±53° [.92 rad] with some Indicators).

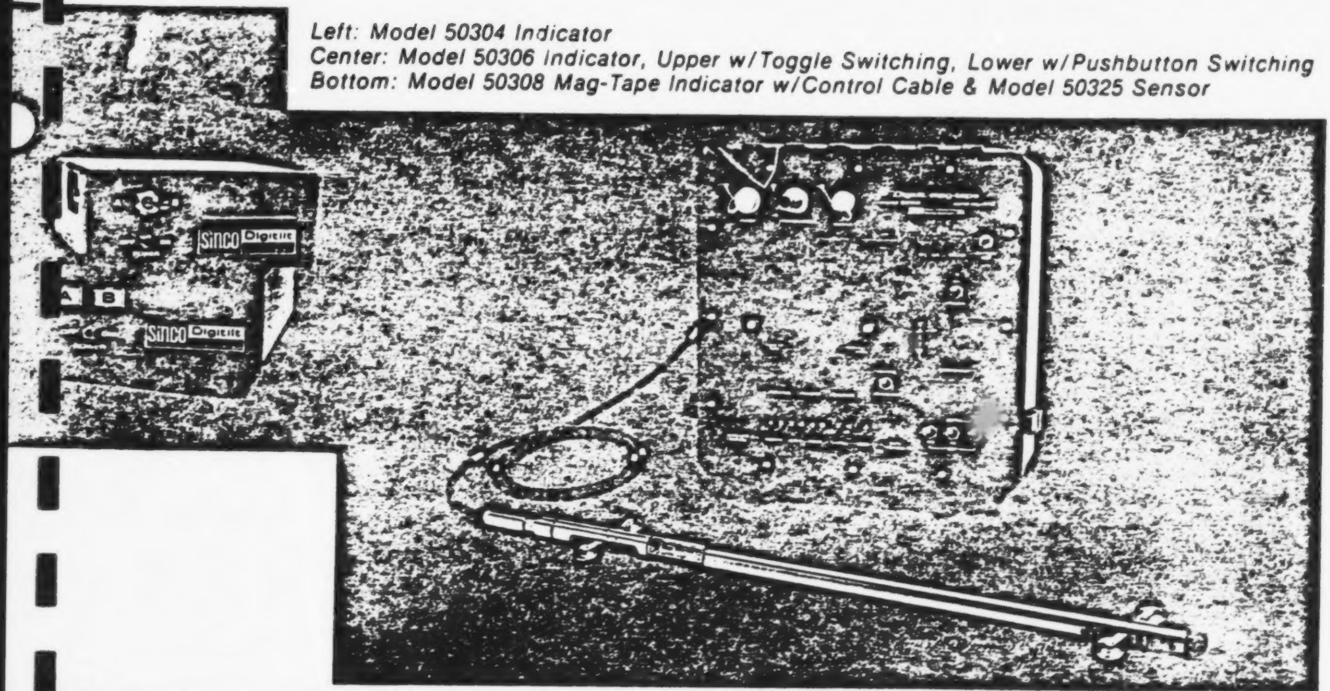
See Table 2 for sensor specifications.

Upper: Stainless Steel Carrying Case
Center: Model 50320 Sensor Lower: Model 50325 Sensor

Indicators

The portable, rugged Digitilt® Indicators utilize digital displays with automatic polarity (direction) signs. Indicators operate on rechargeable internal batteries, external 12-volt battery, or 110/230 VAC line power.

Table 1 lists the various indicators. Model 50304,



Left: Model 50304 Indicator
Center: Model 50306 Indicator, Upper w/Toggle Switching, Lower w/Pushbutton Switching
Bottom: Model 50308 Mag-Tape Indicator w/Control Cable & Model 50325 Sensor

INDICATOR MODEL	DIMENSION	WEIGHT	POWER INTERNAL	POWER EXTERNAL	CHARGER	OPER TIME ON BATT.	DIGITAL DISPLAY	RECORDING CAPABILITY
50309	5x7x7 in (12.7x17.8x17.8 cm)	7.5 lb (3.4kg)	6V, 6Ah	12VDC/ Charger	External	12 hrs**	4 digit LCD	Manual
50306	5.6x2.4x9 in (14.3x6x22.9 cm)	5 lb (2.3kg)	6V, 6Ah	6VDC/ Charger	External	8 hrs	4 digit LED	Manual
50304	10x7x7 in (25.4x17.8x17.8 cm)	11lb (5kg)	6V, 8Ah	110 VAC/ 12 VDC	Internal	10 hrs	4 digit LED	Manual
50308	10.5x15x15 in (26.7x38x38 cm)	35 lb (15.9kg) 40* lb (18.1kg)	6V, 10Ah 6V, 20Ah*	110 VAC/ 12VDC	Internal	8 hrs 16 hrs *	4 digit (A/B) 3 digit (Depth)	Integral Cassette Recorder

Table 1 — Indicators

*Optional battery pack will double operating time and add 5 lbs (2.3kg)

**Below 40°F ambient, operating time is reduced by up to 50% to keep display warm

50306 and 50309 are the standard portable field indicators. Model 50306 incorporates the latest electronics to minimize size yet maintain ruggedness. Model 50304 combines the electronics of the 50306 with an internal battery charger in a small portable case. The 50309 features a liquid crystal display and is environmentally packaged. Mag-tape model 50308 automatically records data on an integral cassette recorder and is environmentally packaged to permit operation under adverse weather conditions.

Cable

In the Digitilt® system, the sensor and indicator are connected with a 0.42-inch (10.7mm) diameter cable which carries the signal and acts as the suspension cable for lowering the sensor into the borehole. The cable has a stranded steel core to bear pulling stresses and eliminate connector and wire breakage. The cable is jacketed with heavy waterproof neoprene and marked externally at one-foot or half-meter intervals for easy depth determination. Metric cables are available on request. Adhesive layers between the stranded steel core, individual wires and the neoprene jacket prevent jacket creep and slippage when the cable is clamped or held by the outer jacket.

Slope Indicator Casing

The casing used for inclinometer readings has four lengthwise grooves spaced at 90° ($\pi/2$ rad) on the inside circumference. These grooves are for guiding the wheels of the inclinometer sensor in the two orthogonal directions of measurement. It is by means of these guide grooves, which control orientation of the sensor, that lateral earth measurements can be measured with a high degree of sensitivity and accuracy.

Slope Indicator casing is available in ABS plastic in three sizes: 3.34" (84.8mm) O.D., 2.75" (69.9mm) O.D., and 1.9" (48.3mm) O.D. Epoxy-coated or uncoated aluminum alloy casing is available in two sizes: 3.38" (85.9mm) O.D. and 2.79" (70.9mm) O.D. The casing has standard lengths of either five feet (1.53m) or ten feet (3.05m). Couplings at the joints are for butt joints or telescoping joints. In situations where large vertical settlements occur, the telescoping joints prevent buckling of the casing.

Vertical Earth Movement

Vertical Earth movements - settlement or heave of foundations and embankments - can also be measured in the slope indicator casing with telescoping joints. This is done by means of a settlement probe and surveyor's tape measuring to each joint in the casing or with a SONDEX Probe and surveyors tape measuring to rings installed around the casing.

Casing Spiral Survey

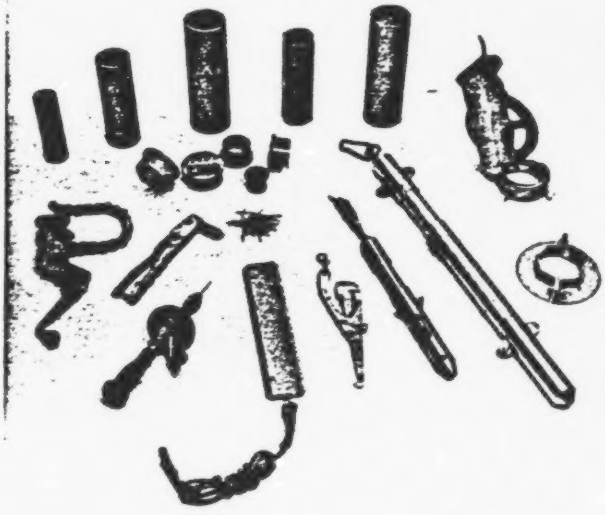
Spiral Checking Instruments are available for rent or purchase for determining the accumulated spiral of a casing from top to bottom as well as at intermediate points. SINCO casing has less than 1° (.018 rad) of spiral per 10-feet (3.05m) when properly installed. However, if a closer determination of spiral is required or if improper casing installation is suspected, the SINCO Spiral Checking Instrument can provide an accuracy of 10 min. of spiral per 5-feet surveyed (.003 rad of spiral per 1.53 meters).

Experience and Field Service

Our staff has over 21 years experience in the installation of inclinometer systems under all field conditions. We can give recommendations on casing types, installation methods, monitoring techniques, data reduction and presentation methods. We can also provide field services for training clients' personnel in all methods of installation, monitoring and field maintenance of the equipment.

Call on the Slope Indicator Company when you need to monitor horizontal displacements, determine pile tip locations after driving, or pile bending under test loads. Sensors can be adapted with special wheel carriages to internally survey pipe piles for their installed profiles or to survey drill rods to locate drill bits and to determine heading direction. Special torque rods are available to control sensor orientation while surveying pipe piles and drill rods.

Since this is a scientific instrument, measurements should be taken, recorded, and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of the personnel used.



Slope Indicator Casing and Accessories

SENSOR	MODEL 50320	50325	MODEL 50320-J	50325-J
Sensitivity	± .0001 foot per 2 feet casing	(same)	± .02mm per 500mm casing	(same)
Total System Accuracy	± 0.3 inch per 100 feet casing	(same)	± 6mm per 25 meter casing	(same)
Wheel Base	24 inches	(same)	500mm	(same)
Overall Length	36.5 inches	30 inches	81.6cm	65.3cm
Outside Diameter, not including wheels	1.69 inches	1.0 inch	42.9mm	25.4mm
Sensors	Two 0.5g closed loop force-balanced servo-accelerometers	(same)	(same)	(same)
Operating Range	0° to 30° (π/6 rad) 0° to 90° (π/2 rad) Special	(same)	0° to 53° (.92 rad) 0° to 90° (π/2 rad) Special	(same)
Cable	0.42-inch O.D., six conductor with 1/16-inch stranded-steel core; waterproof neoprene cover with external marks at one-foot intervals		10.7mm O.D. six conductor with 1.59mm stranded-steel core; waterproof neoprene cover with external marks at 500mm intervals	
Casing	All sizes except 1.9" O.D.	All sizes	All sizes except 48.3mm O.D.	All sizes

Table 2 — Specifications

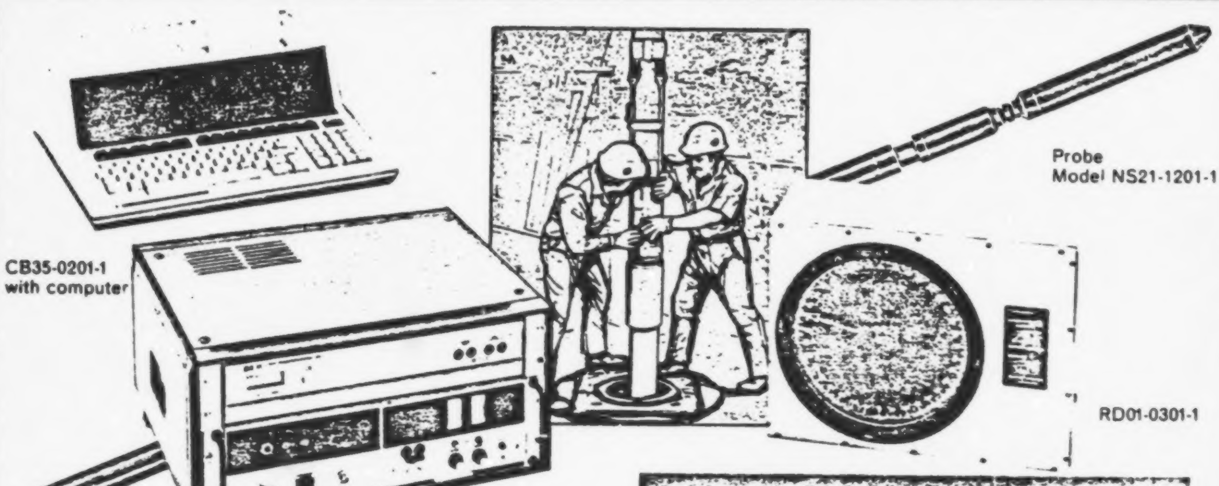
SINCO
Slope Indicator Company
3668 Albion Place North, Seattle, Washington 98103 U.S.A.
TWX: 910-444-2205 (SINCO SEA) cable: SINCO SEA phone: (206) 633-3073

Printed in USA (4-79)

DirectionalSURVEYOR™SYSTEMS

All equipment sold worldwide

Humphrey Inc.


CB35-0201-1
with computer
Probe
Model NS21-1201-1
RD01-0301-1

DrillDIRECTOR™ (STEERING TOOL) FM TRANSMISSION SYSTEM

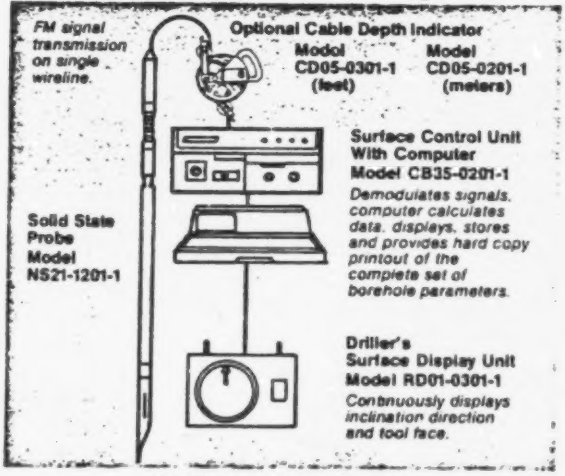
- Gives you continuous readings on hole direction while you're drilling, continuous temperature readout and single shot camera check;
- All solid-state with single wireline multiplexed FM signals;
- Control unit will also run gyro survey probe for complete survey or for downhole orientation.

The DrillDIRECTOR™ steering tool survey system consists of four components ... the survey probe, optional cable depth indicator, surface control unit with computer and the remote display. In operation, the probe's solid state sensor generates FM signals that are transmitted by a single wireline to the surface control unit. The signals are then demodulated in the control unit and fed into the built-in data acquisition system that calculates and displays a complete set of borehole parameters such as slant angle, slant angle bearing, azimuth, time, north-south, east-west and total vertical depth coordinates, dogleg severity, vertical section, tool face, cable depth, probe temperature and reference voltage. This information can be stored on magnetic tape or printed out for a permanent hard copy record (80 column printer optional).

The remote display unit, located at the driller's control station on the drilling rig, continuously displays the hole inclination, direction and tool face and allows the directional driller to keep the mud motor on course by taking corrective action without interrupting the drilling sequence. Multiple remote displays can be used.

The driller can, at the flip of a switch, change from hole direction (high side) steering to steering relative to magnetic north and, at the same time, he can monitor the temperature of the circulating mud.

The DrillDIRECTOR™ steering tool is equipped with a single shot camera to provide a film disc permanent record as a check shot. The film disc confirms the surface data information received from the DrillDIRECTOR™ prior to removing it from the mule shoe.


FM signal transmission on single wireline.
Optional Cable Depth Indicator
Model CD05-0301-1 (feet)
Model CD05-0201-1 (meters)
Surface Control Unit With Computer Model CB35-0201-1
Demodulates signals, computer calculates data, displays, stores and provides hard copy printout of the complete set of borehole parameters.
Solid State Probe Model NS21-1201-1
Driller's Surface Display Unit Model RD01-0301-1
Continuously displays inclination direction and tool face.

SPECIFICATIONS

INPUT VOLTAGE .... 105-130 VAC (47-63Hz)
220 V, 50 Hz optional

MODEL CB35-0201-1 CONTROL UNIT
OUTPUT VOLTAGE TO:

PROBE	0-150 VDC MAXIMUM
REMOTE DISPLAY	+9 VDC REGULATED
CABLE DEPTH	+7 VDC REGULATED

MODEL CB35-0201-1 CONTROL UNIT
OUTPUT CURRENT TO:

PROBE	1.5 AMP
REMOTE DISPLAY	500 MA
CABLE DEPTH	20 MA

OPERATING TEMPERATURE

PROBE	−55°C to + 110°C
CONTROL BOX	+ 5°C to + 40°C
REMOTE DISPLAY	−20° to + 100°C

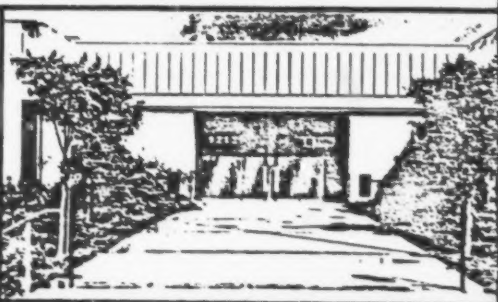
GENERAL OFFICES: 9212 Balboa Ave., San Diego, California 92123 U.S.A.
Phone (619) 565-6631, TWX: 910-335-2001

PLANT II: 9581 Ridgehaven Ct., San Diego, California 92123 U.S.A.

HOUSTON REGIONAL OFFICE (Humphrey Gyros, Inc):
7334 Rampart, Suite 105, Houston, Texas 77081 U.S.A.
Phone (713) 774-2004

PHILADELPHIA REGIONAL OFFICE:
3507 Felton Ave., Cornwells Heights, Pennsylvania 19020 U.S.A.
Phone (215) 752-9292

WICHITA REGIONAL OFFICE: 156 S. Maize Road #1, Wichita, Kansas 67209 U.S.A.
Phone (316) 721-2662



Humphrey Inc.

DirectionalSURVEYING™EQUIPMENT

All equipment sold worldwide

CONTROL UNITS

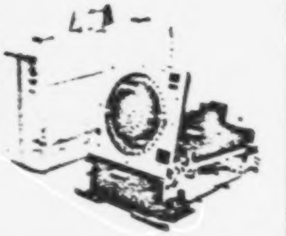
Model CB24 Series. Control units for Model DS17 type control sub. Monitors battery voltage, gyro current and controls electrical or manual cage and uncage functions.

Model PS10 Series. Gyro warm-up unit supplies 30 VDC at 2.5 amps. Equipped for electrical cage and uncage. Has gyro support stand for 1.50" or 2.50" diameter gyros. Operates on 100, 120, 220, 240 VAC, 50/60 Hz.

INSTRUMENT CARRYING CASES

Model IC Series. Available for transporting gyros, angle units, multi shot and single shot cameras and supporting equipment. Aluminum with compartmentalized internal foam cushioning. Model IC08-0101-1 single shot kit shown.

FILM VIEWERS



Model FV03-0101-1. Portable, multi shot film viewer can view either 8mm or 10mm film, and has a large, 6-inch diameter orienting viewing screen with movable scribe line. Furnished with image counter. Picture number digitally displayed on front panel. Removable carrying case.

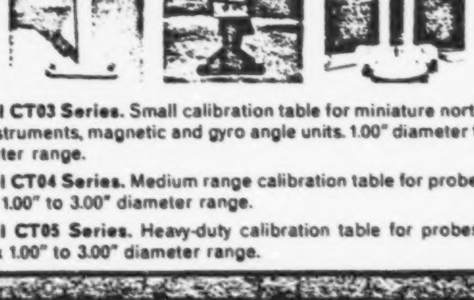
DISC VIEWERS

Model DV02-0101-1. For 1.25" diameter single shot camera disc. Single shot viewer with orientation, center scribe line. Snap-in retaining ring and 2:1 picture magnification.

Model DV03-0101-1. For 1.00" diameter single shot camera disc.

CALIBRATION TEST STANDS

Non-magnetic calibration tables having three readouts for slant angle, slant angle bearing and azimuth.



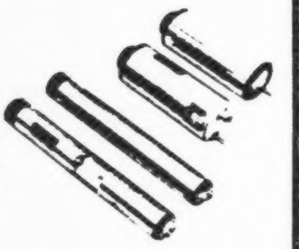
Model CT03 Series. Small calibration table for miniature north seeking instruments, magnetic and gyro angle units. 1.00" diameter to 2.50" diameter range.

Model CT04 Series. Medium range calibration table for probes up to 5 ft. x 1.00" to 3.00" diameter range.

Model CT05 Series. Heavy-duty calibration table for probes up to 15 ft. x 1.00" to 3.00" diameter range.

GYROSCOPES

Four standard 1.50" and 2.50" diameter gyros for precision, single and multi shot downhole surveying and tool orientation. Compatible with AU07 Series angle units and PH02 single shot and PH04 multi shot cameras. Field overhaul kits available. Special compass cards and verniers available with cover glass (quartz lens) upon request.



Model DG29-1100 Series (1.50" diameter). Manual cage. Photographic compass card with vernier and "J" lock.

Model DG29-1400 Series (1.50" diameter). For operation with electrical cage and uncage. Photographic compass card with vernier and "J" lock.

Model DG02-0400 Series (2.50" diameter). Rugged, for larger tools at less cost. Manual cage. Photographic compass card with vernier and "J" lock.

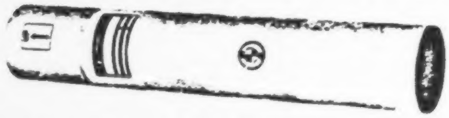
Model DG02-0800 Series (2.50" diameter). Has electrical cage and uncage. Photographic compass card with vernier and "J" lock.

REPAIR KITS

Model RK01 Series Repair Kits available for 1.50" and 2.50" diameter gyros.

Model RK02 Series Repair Kits available for angle units.

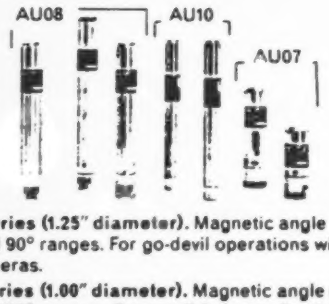
OMNI® DG76 4-GIMBAL GYRO PLATFORM



Model DG76 Series. GyroSURVEYOR® 2.5" diameter platform for use with solid state, single wire, multiplexing or standard conductor cables. Eliminates gross gimbal errors, giving true position for any slant angle through 180° 360° slant angle bearing and 360° azimuth or tool face orientation. Complete running gear available.

MAGNETIC AND GYRO ANGLE UNITS

Shown with thread protectors.



Model AU08 Series (1.25" diameter). Magnetic angle units. Available in 5° 12° 20° and 90° ranges. For go-devil operations with Model PH02 single shot cameras.

Model AU10 Series (1.00" diameter). Magnetic angle units. Available in 10°, 90° and 120° ranges. For small hole applications where heat shields (1.25" OD) are required. Used with Model PH05 multi shot cameras and PH10 single shot cameras.

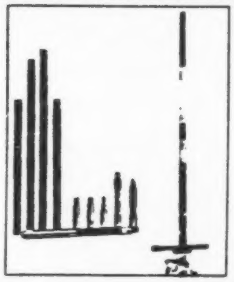
Model AU07 (1.50" diameter). Gyro angle units. Available in 2° 5° 12° 34° and 90° "J" lock. Aluminum construction. Used with Models DG02 and DG29 gyros and Models PH02 single shot and PH04 multi shot cameras.

DirectionalSURVEYOR™SYSTEMS
All equipment sold worldwide

Humphrey Inc.

PHOTOGRAPHIC SURVEY SYSTEMS

Call or write for detailed brochures. Self-contained, portable, battery-operated systems. 1.75" diameter system shown. Basic Model AU07 Series gyro angle units can be used interchangeably with single shot or multi shot cameras. Many variations available. Heat shield systems available on request.



GYROSCOPIC SINGLE SHOT CAMERA SYSTEM

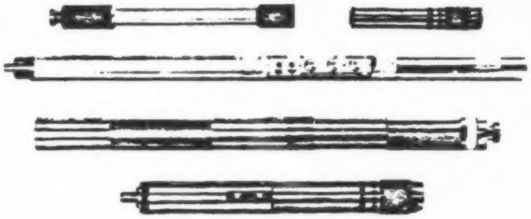
Model DS17-0502-1 (1.50" diameter gyro). Completely self-contained single shot survey system. 1.75" diameter gyro probe running gear equipped for tool orientation.

GYROSCOPIC MULTI SHOT CAMERA SYSTEM

Model DS17-0501-1 (1.50" diameter gyro). Completely self-contained multi shot surveying system. 1.75" diameter gyro probe running gear.

Model DS08-0101-1 (2.50" diameter gyro). Completely self-contained multi shot surveying system. 3.00" diameter to 1.75" diameter gyro probe running gear.

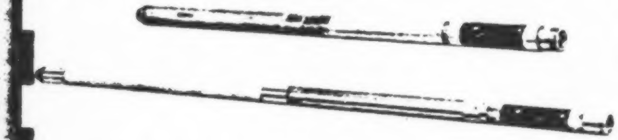
SINGLE SHOT CAMERAS



Model PH10-0101-1 (1.00" diameter). Single shot camera.

Model PH02-0201-1 (1.25" diameter). For standard single shot or gyroscope orientation. Camera includes battery pack and electronic timer. Removable lens adapters with light source shut-off valve make it readily adaptable to special angle units. Stainless steel and titanium construction.

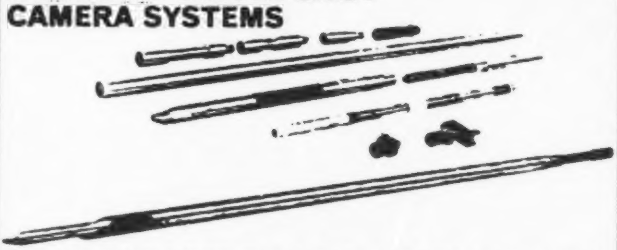
MULTI SHOT CAMERAS



Model PH04-0101-1 (1.25" diameter). Uses 10mm film with removable cassette. Has battery pack and electronic timer with time delay settings of 1,2,4, and 8 minutes. Operates with Model AU07 Series and Model AU08 Series gyro or magnetic angle units.

Model PH05-0101-1 (1.00" diameter). Uses 8 mm film with removable cassette. Has battery pack and electronic timer with time delay settings of 1, 2, 4, and 8 minutes. Operates with Model AU10 Series magnetic angle units only. Heat shields available.

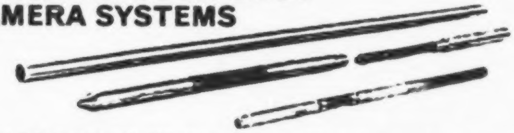
MAGNETIC SINGLE SHOT CAMERA SYSTEMS



Model DS10-0101-1 (1.75" diameter). Go-devil 1.25" diameter single shot, muleshoe orientation. Running gear shown with complete single shot camera, battery pack and angle unit.

Model DS13-1001-1 (1.75" diameter). Go-devil 1.00" diameter single shot, muleshoe orientation with HS01-0101-1 heat shield.

MAGNETIC MULTI SHOT CAMERA SYSTEMS



Model DS10-0201-1 (1.75" diameter). Multi shot surveying system for sand line operations. Equipped with 1.25" diameter multi shot camera Model PH04 Series.

Model DS13-0801-1 (1.75" diameter). Hot hole multi shot surveying system for sand line operations. Equipped with 1.00" diameter multi shot camera and HS01-0101-1 heat shield.

Model DS13-0601-1 (1.25" diameter). Multi shot surveying system for sand line operation. Equipped with 1.00" diameter multi shot camera Model PH05 Series.

HEAT SHIELDS

Model HS01-0101-1. For 1.00" diameter single shot or multi shot cameras.

Model HS04-0101-1. For 1.25" diameter single shot or multi shot cameras. Available with complete running gear.

FILM LOADERS

Contain 50 single shot discs and operate with single shot camera systems. Non-corrosive plastic and stainless steel construction.

Model FL03-0101-1.
For 1.25" diameter single shot cameras.

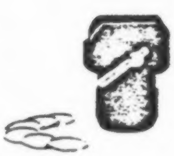
Model FL05-0101-1.
For 1.00" diameter single shot cameras.

FILM DEVELOPERS

For single shot camera systems. Equipped with light trap and removable field developing reservoir. Non-corrosive plastic and stainless steel construction.

Model DF03-0101-1. For 1.25" diameter single shot cameras.

Model DF05-0101-1. For 1.00" diameter single shot cameras.

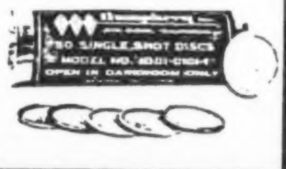


SINGLE SHOT DISCS

Packaged 50 discs per roll. Suitable for certain other brands of single shot tools. Record envelopes available.

Model ID01-0101-1. For 1.25" diameter single shot cameras.

Model ID02-0101-1. For 1.00" diameter single shot cameras.



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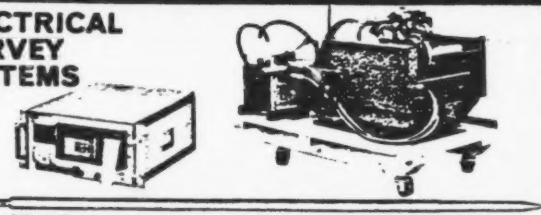
All equipment sold worldwide

ELECTRICAL SURVEY SYSTEMS



Model CB10 Series. Control unit with all power supplies, digital data display and automatic printer. Has 5-channel switch for automatic or manual selective readings.

Model CR11 Series. Hydraulic powered cable reel for smooth, variable speed control. Cable depth indication by mechanical counter as well as electronic counter to interface with data acquisition instrumentation in the CB10. Hydraulic pump is powered by a 1 HP motor (120-230 VAC, 50/60 Hz). Automatic level wind is built in. Clutch allows disconnect for free wheeling and a dual disc brake with adjustment screw to set drag.

This complete, portable wireline survey system operates on standard electrical power (120-230 VAC, 50/60 Hz) and is accurate to one foot per 1000 feet and gives continuous downhole readings to 4,000 feet on slant angle, slant angle bearing, azimuth, time, and cable depth at speeds of up to 100 feet per minute. Greater depths are possible with other cable reels offered. Mounts easily on back of a small truck. All information is instantly displayed on the surface console and a permanent record is provided by an automatic printer. Computer and software available. Single or multiple conductor transmission available.

SINGLE WIRELINE SURFACE RECORDING SYSTEMS

Model GP26-0501-1. Single wireline, multiplexing, gyro system for use with CB35-0201-1 surface control unit. 1.75" diameter. Output functions include slant angle 0°-45°, slant angle bearing 360° and azimuth 360°.

Model NS21-0701-1. Single wireline, multiplexing, north seeking, flux gate system for use with CB35-0201-1 surface control unit. 1.75" diameter. Output functions include slant angle 0°-90°, slant angle bearing 360°.

Computer software is required.

ELECTRICAL SURVEY PROBES

Model NS14-0302-1. Magnetic north seeking flux gate type probe. Provides full range of measurement for drilled holes. Full 360° slant angle bearing, 1.5° to 45° slant angle. For use with CB23 control unit and CR02-0600-0 Series cable reels.

Model NS08-0400 Series. Magnetic flux gate type north seeking instrument. 28 VDC input, 1.5" diameter, 7.5 VDC for 90° full scale output angles. Provides X (east west) and Y (north south). Normally used with customer's own running gear.

GYROSCOPIC SURVEY PROBES

Model GP06 Series. Gyro-SURVEYOR® 1.75" diameter probe using X (east west) and Y (north south) sensors and azimuth. Output range X and Y 7.5 VDC for 90°. Four-pin cable head. Outputs are computated automatically or manually on surface command.

Model GP07-0900 Series. GyroSURVEYOR® 3.0" diameter probe. 2.5" diameter gyroscope system. Slant angle 0° to 90°, slant angle bearing 358°, azimuth 358°. Four-pin cable head. 33-40 VDC. Software available.

Model GP07-0800 Series. GyroSURVEYOR® 1.75" diameter probe. 1.5" diameter gyroscope system. Slant angle 0° to 45°, slant angle bearing 358°, azimuth 358°. Four-pin cable head. 33-40 VDC. Software available.

MiniMAG™ 3-AXIS MAGNETIC SURVEY TOOL

Minimum diameter magnetic survey tool provides DC outputs of inclination angle and relative bearing angle referenced to magnetic north. Surface recording and computing systems available.

Model NS21-1001-1. MiniMAG™ 1½" diameter probe (includes heat shield) is suited to high temperature use up to 150°C. Without heat shield probe diameter measures 1¼". Operates on 28 VDC and is 9 ft. long.

SS MULTI SHOT SURVEY SYSTEM

Computer with graphics

Surface control unit

This borehole survey system, with digital memory, accepts up to 512 readings. Basic system includes choice of four battery-powered memory probes, cable depth indicator, and surface control unit with built-in printer.

In field use, the control unit and probe are automatically synchronized prior to starting a survey. Cable depth and time readings are recorded in the control unit, slant angle and slant angle bearing or X and Y coordinates are memory-stored by the self-contained probe. When the probe is returned from the survey it is reconnected to the control unit, and the stored data of both the control unit and the probe are automatically synchronized, combined and printed out in less than 10 minutes.

Option 1. Features a desk-top Model HP-85B Computer with 64K bytes of RAM, consisting of BCD interface unit and software with graphics. Compatible software programs are available. Data transfers of up to 512 readings when using north seeker probes and slightly less when using gyro probes allowed with the CB29A1 or CB29D1 program. System provides graphic display and printout of both borehole plan and radial views with an average processing time less than 30 minutes for the average borehole.

Option 2. Same as Option 1 except printer is left out and all data is presented through the HP-85B Computer.

Probes. Four different memory probes are available—two north seeking, two gyro types—with either direct angle or X-Y axis outputs, to suit most borehole survey requirements. Probes are completely self-contained with battery pack and run on a single sand line with no conductor cable required.

Model NS24-0100 Series. North seeking type flux gate probe for output of slant angle and slant angle bearing. Used for boreholes with angles up to 60 degrees and where no magnetic fields exist in immediate area.

Model NS24-0200 Series. North seeking type flux gate probe with sensors for X and Y axes. Used for boreholes with inclination angles up to 60 degrees.

Model GP26 Series. Features gyroscope and potentiometer for direct output of slant angle and slant angle bearing for boreholes with angles up to 60 degrees. Used where magnetic fields exist.

Model GP23 Series. Equipped with X and Y axis sensors and azimuth potentiometer for accurate vertical surveying. System can be used for surveying angles up to 45°. Up to 340 readings in memory.

Model CD05-0200 Series. Cable depth indicators. Consists of main cable wheel designed for long wear, two idler wheels, and geared electronic pulse transmission unit. Sealed ball bearings used throughout. For metric measurements, providing 1 pulse/0.1 meter to control unit.

Model CD05-0301-1. For English measurements, providing 1 pulse/foot to control unit.

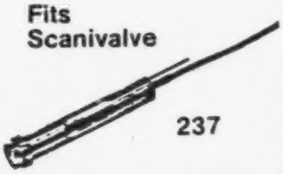
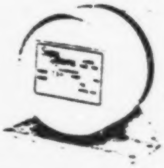
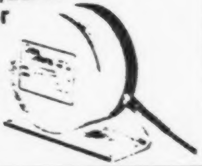
Model CB29-0101-1. Surface control unit. Combines and prints out stored data of control unit with probe data. Format of four lines for each reading consisting of reading number, cable depth, slant angle, and slant angle bearing. Model GP23 Series Probe, in addition, provides azimuth reading.

COMPUTER WITH GRAPHICS

Small lightweight HP-85B Computer interfaces with control unit. "Mag" tape cartridge or diskette software provides complete and accurate computation of up to 512 borehole readings in less than 20 minutes including radial and plan view graphics. Compatible, customized software programs are available.

SURFACE CONTROL UNIT

Stand-alone control unit with data printer and connector for BCD interface. Option 1 includes 64K byte, portable, desk-top computer (HP-85B) with BCD interface and software for complete computation and graphic printout of all borehole parameters.

 Fits Scanivalve 237	 239 & 239E	 Setraquartz™ Sensor 250
Flush Diaphragm Differential Pressure Absolute Pressure	Absolute Pressure Gage Pressure Differential Pressure	Barometric Pressure Absolute Pressure Gage Pressure
Gas or liquid Compatible with stainless steel	Gas or liquid Compatible with stainless steel, aluminum[1]	Clean, dry, non-corrosive gas, such as air
Clean dry non-corrosive gas	Clean dry non-corrosive gas	
0 to 1 psia	0 to 1 psia (51.7 Torr)	Barometric, 0 to 20 psia
0 to 5 psia	0 to 5 psia (258.5 Torr)	0 to 30 psia
0 to 0.2 psig	0 to 0.02 psig	
0 to 500 psig	0 to 100 psig	0 to 30 psig
0 to 0.2 (or ±0.1) psid	0 to 0.02 (or ±0.01) psid	
0 to 500 (or ±50) psid	0 to 100 (or ±50) psid	
0 to 0.2 psiv	0 to 0.2 psiv	
0 to 10 psiv	0 to 10 psiv	
30 psig	200 psig[2]	
½"dia., Flush diaphragm	⅛"-27 NPT, internal	⅛"-27 NPT, internal
2 to 5 ms	2 to 5 ms	10-20 ms
0.27%	239: 0.14% | 239E: 0.23%	0.06%
.015 max. .01 max.	.01 max.[6] | .05 max.[6] .01 max. | .05 max.	.001 max.(.002% Barom.) .001 max.

Gage Pressure:	Pressure measured relative to ambient atmospheric pressure. Referred to as pounds per square inch (gage) or psig.
Absolute Pressure:	Pressure measured relative to high vacuum. Referred to as pounds per square inch (absolute) or psia.
Vacuum:	Vacuum measured relative to ambient atmospheric pressure. Referred to as pounds per square inch (vacuum) or psiv.

POOR

QUALITY

ORIGINAL